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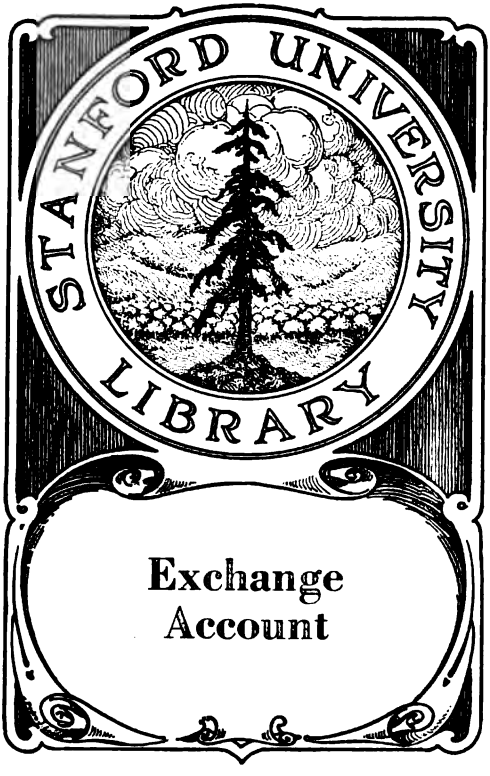

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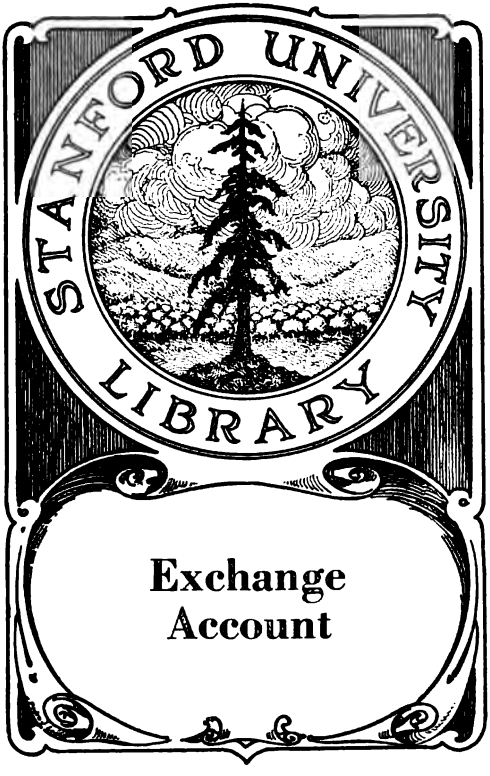

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THE MYXOMYCETES AND FUNGI OF COLORADO

ELLSWORTH BETHEL, A. M.

AND

WM. C. STURGIS, Ph. D.

NO. 1. THE MYXOMYCETES OF COLORADO

W. C. STURGIS

COLORADO SPRINGS, COLORADO

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NOTE.

The series of papers, of which the present one is the first, is intended to cover the mycological flora of Colorado. The Rocky mountain region has heretofore received little attention on the part of mycologists, first, because the rich and varied phanerogamic flora has engrossed the attention of botanists, and secondly, because it has been assumed that such an arid region offered no attractions to mycologists. This assumption, however, is unwarranted. During the past ten years or more, Mr. Bethel has collected a vast quantity of material in all groups of fungi, and the fact has become apparent that the region explored, so far from being devoid of these plants, presents an extraordinarily rich field for the mycologist. That the present paper includes almost one hundred species and varieties of *Myxomycetes* from the state of Colorado alone, is certainly a striking and unexpected fact. In preparing this series of papers each of the collaborators will, as a rule, treat the group or groups in which he has specialized and will be solely responsible for his own work, but in certain cases the work will be done conjointly.

Although much material is already on hand, collectors and students throughout the State are earnestly requested to send in specimens. All specimens received in this way will be determined and due credit given to the collector.

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THE MYXOMYCETES OF COLORADO.

WM. C. STURGIS.

INTRODUCTION.

The *Myxomycetes,* or *Mycetozoa,* form a natural group of organisms bearing an indefinite relationship on the one hand to the *Protozoa* and on the other to certain of the lower *Fungi.* So vague is this relationship, however, that, without stretching the observed facts, they cannot be placed in either group. Nor indeed, can it be said with any certainty whether they should be classed as plants or as animals; nevertheless the study of these organisms is, and always has been, mainly in the hands of botanists, probably because in their reproductive phase they bear a certain external resemblance to the fungi, many of them having been included among the "puff-balls" by the earlier writers.

LIFE HISTORY.

Briefly, the *Myxomycetes* are characterized by a vegetative phase, consisting of a naked, venulose or pulvinate, protoplasmic mass, often attaining a large size and possessing a striking color, and exhibiting streaming movements within its substance, as well as amœboid movements of the whole mass. This is known as the *plasmodium.* The plasmodium has a distinct affinity for water and obscurity; hence it usually affects the lower surface of rotten logs, the interstices of bark or wood, the interior of damp leaf-heaps and similar locations. Before passing over to the reproductive phase, the plasmodium moves toward the light and to a drier portion of the substratum. Here it becomes transformed into fruiting bodies of manifold forms according to the species. In a single instance the fruiting body consists of columnar prolongations of the plasmodium, which rise erect and eventually produce on their surfaces vast numbers of *spores.* Usually, however, this phase is in the form of *sporangia,* which may be of various shapes, stalked or sessile, simple or compound, spherical or elongated *(plasmodiocarps).* Frequently the fruiting body consists of a multitude of convo-

luted sporangia, inextricably united and forming a mass of considerable size known as an *"æthalium."* In any case, however, the interior of the sporangium, at first similar to the plasmodic matter from which it was derived, becomes differentiated before maturity into spores and, in many cases, into delicate threads which may be either free *(elaters)* or united into a network known as the *capillitium.* Meantime the sporangium itself develops a more or less firm wall, on the surface of which may be deposited, in the form of crystals or granules, a varying quantity of lime heretofore held in suspension by the plasmodium. Such deposits of lime, together with refuse matter, may also occur in the stalk and in the threads of the capillitium. Frequently the stalk is prolonged upward into the sporangium and appears either as a rounded body at the base of the sporangium, or elongated, sometimes to the very apex of the sporangium. This is known as the *columella* and from it spring the main branches of the capillitium.

The spores are usually spherical bodies with a firm, colored wall which is either smooth or marked with papillæ, spines, or raised bands. Under suitable conditions the spore germinates and produces a motile, amœboid body known as a *swarm-spore.* Eventually neighboring swarm-spores unite and by their union form the plasmodium.

Such in brief outline is the life-cycle of an ordinary *Myxomycete.*

As a rule they are to be looked for in warm, damp situations. It is therefore rather surprising to find them occurring in great variety and abundance under the rather arid conditions prevailing in Colorado and at every degree of altitude up to 10,000 feet. Of course there must be, for their best development, a certain amount of protection and moisture. Hence they are to be looked for, as a rule, in shady cañons or in the forests where fallen logs decay and hold the moisture. In such places we find them growing luxuriantly.

COLLECTION AND PRESERVATION.

In collecting *Myxomycetes* the most convenient method is to detach each colony together with a portion of the substratum and wrap the whole in a twist of tissue paper. In this way even the more delicate forms can be safely carried. To preserve them it is only necessary to let them remain exposed to the air until thoroughly dry and then glue them to cards cut to fit oblong paper slide-boxes and removable

therefrom. If the two ends of the card are bent up at right angles they will serve to keep the card firmly in the box when the cover is in place.

It is often advisable to collect a plasmodium and allow it to develop, in which case it may be placed in a tin box and held in place by damp paper or moss. Care, however, must be taken that the plasmodium does not come in contact with the box or the packing and that a sufficient quantity of the substratum be removed with the plasmodium to insure its further development. As soon as practicable the specimen should be removed from the box and placed on damp paper under a bell-jar at the ordinary room-temperature, when, if all goes well, it will be transformed into the fruiting bodies within a few hours.

MICROSCOPIC EXAMINATION.

For the microscopic examination of the *Myxomycetes* it is only necesary to pick off a single sporangium or bit of an æthalium, place it in a drop of alcohol on a glass slide in order to remove the air, then replace the alcohol with a drop of water and cover with a cover-glass. For permanent mounts glycerine jelly or Canada balsam may, after due preparation of the specimen, be used. The writer, however, prefers a mixture of glycerine and acetic acid in equal parts, boiled and then cooled. Of course this is ruinous to any specimen containing lime, in which case plain glycerine is used. A drop either of the mixture or the glycerine is placed on one end of the slide bearing the specimen mounted in water; to this a few drops of water are added and thoroughly mixed by stirring with a needle; the mixture is then drawn up to the edge of the cover-glass and the slide is placed in a shallow drawer or other receptacle where it will be free from dust. In the course of a week or ten days the water and the acid will have evaporated and the specimen is now in pure glycerine. The cover-glass is now ringed with King's Red Lacquer Cement until the ring is perfectly opaque. Specimens so prepared are free from shrinkage and distortion and may be kept indefinitely.

LITERATURE.

The literature of the *Myxomycetes* is very extensive, but for the beginner one of two books only is essential, Macbride's *North American Slime-Moulds,* published by the Macmillan Co., New York, or Lister's *Monograph of the*

Mycetozoa, published by the British Museum. The former is by far the best account ever published of the American forms; the latter has a wider scope and is intended to include all known species.

In preparing the present paper the writer intended at first to make it a mere list of the species heretofore found in Colorado. But during the three years that it has been in course of preparation, the amount of material has become so large, the number of persons who have shown interest in this group of organisms has so increased, and so many forms demanding more than a brief notice have been added to the collection, that it has seemed best to enlarge the scope of the paper so as to make it in some degree a beginner's guide to the *Myxomycetes* in general and a more or less critical survey of the Colorado species in particular, by means of which those interested can determine the genus and possibly the species. To this end the writer has made use of Mr. Lister's Synopsis of the Orders and Genera included in his Monograph, selecting, however, only those genera at present known to occur in Colorado.

KEY TO THE ORDERS AND GENERA OF MYXOMYCETES KNOWN TO OCCUR IN COLORADO.

A. Spores developed outside the Sporophores. *Ceratiomyxa.*

AA. Spores developed inside a Sporangium.

B. Spores violet, violet-brown, or pale ferruginous.

C. Sporangia provided with lime.

D. Lime in minute granules. *(Physaraceae.)*

a. Capillitium charged with lime throughout. *Badhamia.*

b. Capillitium with lime-knots only.

* Fructification compound, (æthalioid) *Fuligo.*

** Fructification simple.

§ Sporangium wall membranous, calcareous. *Physarum*

§§Sporangium wall cartilaginous.

Sporangia plasmodiocarps *Cienkowskia.*

Sporangia with a lid *Craterium*

Sporangia ovoid, shining *Leocarpus*

c. Capillitium without lime-knots *Diderma*

d. Lime confined to stalk and columella *Diachæa*

DD. Lime in crystals. *(Didymiaceae.)*

a. Fructification simple, *Didymium*

b. Fructification compound. *Spumaria*

CC. Sporangia without lime *(Stemonitaceae)*

a. Sporangium wall evanescent.

Capillitium forming a net at surface of sporangium *Stemonitis*

Capillitium not forming a surface-net *Comatricha*

Capillitium springing from apex of columella only . *Enerthenema*

b. Sporangium wall somewhat persistent, iridescent. *Lamproderma*

BB. Spores variously colored, never violet

a. Capillitium wanting, or not forming a system of uniform threads.

* Sporangium-wall with granular deposits, netted above, except in *Lindbladia*. *(Heterodermaceae)*

§ Sporangia sessile, compacted *Lindbladia*

§§Sporangia stalked

Network irregular *Cribraria*

Network of parallel ribs extending longitudinally from base to apex *Dictydium*

** Sporangium-wall without granular deposits; sporangia tubular, compacted *(Tubulinaceae)*

Sporangia without columella *Tubulina*

*** Sporangia combined into an æthalium *(Reticulariaceae)*.

Sporangium-walls represented by 4-6 straight threads extending from base to apex. *Dictydiæthalium.*

Sporangium-walls with large round perforations. *Enteridium.*

Sporangium-walls incomplete, frayed out. *Reticularia.*

b. Capillitium present, a system of uniform threads.

* Capillitium marked with spirals. *(Trichiaceae)*

§ Capillitium of free elaters. *Trichia*

§§ Capillitium combined into a net. *Hemitrichia.*

§§§ Capillitium of fasciculate threads, repeatedly bifurcating. *Prototrichia*

** Capillitium abundant, marked with cogs, half-rings, spines or warts *(Arcyriaceae)*

§ Sporangia stalked, wall evanescent. *Arcyria.*

§§ Sporangia sessile, wall persistent, thick. *Perichæna.*

*** Aethalioid. Capillitium of smooth or wrinkled tubes. *Lycogala*

CERATIOMYXA. *Schroeter.*

CERATIOMYXA MUCIDA, *(Pers.) Schroet.*—This common species occurs everywhere throughout the region explored. The following localities indicate the range:—Bear Creek Cañon, Colorado Springs, (Hall); Boulder, (Bethel & Sturgis); Tolland, (Bethel); San Juan Mts., (Bethel); Ouray, (Bethel).

The so-called *var. porioides, A. & S.* has not been reported from Colorado, a fact which adds weight to the view that the two forms are specifically distinct.

BADHAMIA, *Berkeley.*

BADHAMIA PANICEA, *(Fr.) Rost.* According to Macbride, "this seems to be a purely western species." Wherever fallen logs of cottonwood or box-elder are found in damp situations, the whitish plasmodium occurs in abundance, developing into the small, gray, crowded or scattered sporangia. At Boulder the species is especially abundant, occurring in company with *B. populina, List,* and related forms. It has also been collected at Fort Collins, (Bragg), and a limeless form has been found at Golden, (Bethel).

The specimens on box-elder usually show smaller and more densely clustered sporangia than those on cottonwood. Occasionally the sporangia are stipitate, and more rarely forms occur in which the capillitium shows a few short hyaline threads connecting the lime-knots as is noted by Lister (Mon. p. 34) in the case of the varietal form *B. verna, Rost.*

BADHAMIA POPULINA, *List.* During the summer of 1906 numbers of specimens of a *Badhamia* were sent in by Mr. Bethel, chiefly from Denver and Boulder. The white, gray or pinkish sporangia occurred usually in dense clusters, rarely as separate individuals, on the bark of cottonwood and box elder. In most cases the sporangia were supported on long, membranous, straw-colored stalks. These features, together with the fact that the spores were in clusters of eight to fifteen or more individuals, were so distinctive of *Badhamia capsulifera, (Bull.) Berk.,* that the specimens were at once referred to that species. Upon closer examination, however, the spores were found to exhibit a peculiar feature, being marked with more or less distinct bands or

ridges dividing the surface into three or four triangular areas and a corresponding polygonal area at the broader end. This feature was not always apparent, the specimens on box-elder showing only occasional and very faint bands. At first these bands were taken to be mere pressure-ridges produced by the mutual compression of the spores as they formed in the clusters, but on looking over the literature it was found that Mr. Lister had described, under the name *Badhamia populina,* a species similar to *B. capsulifera* but distinguished from it by a white instead of a chrome-yellow plasmodium and spores banded precisely as in our specimens. (Journ. of Botany: Vol. 42, May, 1904, p. 129.) This led to a personal investigation of the plasmodium, when the latter was found to be uniformly of a whitish color without a tinge of yellow. Specimens were submitted to Mr. Lister and were determined by him as *B. populina.*

Were the banded spores the only feature in which our specimens differ from *B. capsulifera,* they might not serve as a distinctive feature, but taken in connection with the white plasmodium it seems at present advisable to follow Lister in regarding *B. populina* as a distinct species. As to its occurrence in this country, it is probably more widely spread than is at present supposed, having been collected as *B. capsulifera.* The color of the plasmodium is usually overlooked by collectors and, in the present instance, the banding of the spores becomes apparent only with high magnification. Macbride makes no mention of the color of the plasmodium in either *B. capsulifera* or in the related species, (a *variety,* according to Lister), *B. papaveracea.* Under date of October 27th, 1906, Mr. Lister writes: "We have never received our typical European form of *B. hyalina* (*B. capsulifera*) from America. We have had *var. B. papaveracea* sixteen times. All you have sent from Colorado with white, heaped-up sporangia and white or cream-colored plasmodium, are, we believe, *B. populina.*" As above remarked, while it may seem probable that in *B. populina* we have only a marked variety of *B. capsulifera,* there can be no certain conclusion unless specimens are found showing a yellow plasmodium and banded spores, and for the present the name *B. populina* is retained for the form with white plasmodium and more or less distinctly banded spores. It has thus far been collected at Boulder, (Bethel and Sturgis); Morrison, (Bethel); Denver, (Bethel) and Fort Collins, (Bragg).

BADHAMIA VERSICOLOR, *List.* This interesting species was first collected by Mr. Bethel at Boulder in July, 1906, and later by Mr. Bethel and the present writer in the same locality. In both instances it occurred on the bark of box-elder, often in company with *B. populina.* Specimens were submitted to Mr. Lister and determined by him. Since it has not before been reported from America and the original description is not readily accessible, the latter is here given in full.

"Plasmodium? Sporangia sessile, sub-globose, 0.3-0.5 *mm. diam., pure grey or grey with a tinge of flesh-colour, scattered or in small groups; sporangium-wall hyaline, with innate clusters of lime-granules, the lime sometimes scanty or wanting; columella none; capillitium a coarse network of broad or narrower bands densely charged throughout with lime; in some sporangia the granules contained in the capillitium are white, in others apricot-coloured; spores ovoid or somewhat cuneate, arranged in clusters of ten to forty or more, purple-brown and minutely warted on the broad end, pale and smooth elsewhere,* 10 *x* 8—12 *x* 7 *μ* (Jour. of Bot., March, 1901, p. 81.)

The small size of the sporangia would readily cause this species to be overlooked, were it not that they are gregarious, giving the appearance of minute whitish beads sprinkled thickly over the bark. The sporangia are rugose or wrinkled; the base is thickened and of a dark brown color; the lime-knots as well as the sporangium-wall usually show a distinctly yellowish color. The only difference between the Boulder specimens and those described by Lister is that in the latter the spores are in larger clusters.

The species is closely related to *B. capsulifera,* from which, however, it is readily distinguished by the habit and the minute size of the sporangia.

BADHAMIA NITENS, *Berk.* This rare species has been hitherto reported only from England and it is interesting to find it occurring in typical form in the mountains of Colorado. The specimens before us were all collected by Mr. Bethel in August, 1905, on the bark of *Abies concolor* at Ouray, Colo. The greenish-yellow color of the lime in the sporangium-wall and capillitium render it easily distinguishable among the *Badhamias* with clustered spores.

BADHAMIA ORBICULATA, *Rex.* Some confusion has, in the past, existed regarding this species. It is undoubtedly related to both *B. panicea* and *B. macrocarpa,* indeed Mr.

Lister placed it as a variety of the latter species (Mon. p. 34), though in a letter to the writer dated Dec. 15th, 1906, he states that this view was mistaken, being based on insufficient material. It is undoubtedly an autonomous species, differing from *B. panicea* in the short blackish stalks of the stipitate sporangia, but especially in the discoid or annulate form of the sporangia. The smaller, paler spores serve to distinguish it from *B. macrocarpa*. The latter species has not yet been reported from Colorado and seems to be very rare throughout the United States.

The specimens of *B. orbiculata* before us were all gathered in Boulder in September, 1906, by Mr. Bethel and the writer. They occurred uniformly on the bark of cottonwood. With the typical form there occurred in some abundance a form consisting of small, sessile, very much appressed plasmodiocarps with a capillitium of straight, acutely-branching, calcareous rods uniting the lower and upper surfaces of the plasmodiocarp. So marked were these features that they appeared at first to indicate a specific distinction, but further examination showed the presence of intergrading forms apparently connecting the plasmodiocarps and the typical sporangia. So different, however, are these two forms in appearance and in the structure of the capillitium, that it is quite possible that future gatherings may prove the applanate forms to be worthy of at least a varietal position under *B. orbiculata*.

BADHAMIA UTRICULARIS, *(Bull.) Berk.* This species is included in a list of *Myxomycetes* from Colorado in the herbarium of the State University of Iowa, furnished by Professor Macbride. A scanty, immature specimen was found by Mr. Bethel at Tolland, in September, 1906.

PHYSARUM. *Persoon.*

PHYSARUM VIRIDE, *(Bull.) Pers.* This species occurs commonly throughout the State and in all of the three varieties, *luteum, aurantium* and *incanum*. The last-named variety very closely resembles *P. nutans, Pers.*

The *var. aurantium* has been collected at Colorado Springs, (Shantz); Tolland, (Bethel); Glen Park, (Sturgis). *Var. luteum* at Glen Park, (Sturgis); Boulder and Tolland, (Bethel). *Var. incanum* at Boulder and Tolland, (Bethel), and Manitou Park, (Sturgis).

PHYSARUM NUTANS, *Pers.* Much difficulty attends the definition of this species owing to the extreme diversity of

views held by the various authorities regarding this and related species.

Typical *P. nutans* is not difficult to recognize. The slender, non-calcareous stipe, the nodding sporangia, the white lime-knots and the rather pale, violet-brown, almost smooth spores, are sufficiently diagnostic. This form is the *Tilmadoche alba, (Pers.)* of Macbride's "Slime-Moulds," and is represented in our collection by specimens from Colorado Springs, (Shantz); Tolland, (Bethel); Boulder, (Bethel and Sturgis); Glen Park, (Sturgis).

It grades almost imperceptibly into a form with larger spherical sporangia erect upon slender or stout sulcate stipes free from lime and varying in color from pale brownish to almost black, and with dark, purplish-brown, rather spinulose spores. This is the *P. compressum, A. & S.* of Lister's Monograph, of which *var. β* is the common form in this country. It is also the *P. nephroideum, Rost.* of Macbride's "Slime-Moulds," although that name is taken by that author to include forms with stalks charged throughout with lime, as, *e. g.* in Ell. & Ev., N. A. F. 2694. Between these two extremes occur a multitude of forms some of which are placed by Lister as varieties of *P. nutans,* while other authorities regard them as species. Thus Lister relegates the name *P. leucophaeum, Fr.* to varietal rank, whereas Macbride maintains the validity of the species, though there is an irreconcilable difference of opinion as to what that name really applies to. Lister applies it to an erect form with globose densely calcareous sporangia; Macbride to a delicate form with scanty deposits of lime represented by Ell. & Ev., N. A. F. 2693. That specimen, however, with its nodding sporangia and pale spores, appears to be typical *P. nutans* with less lime than usual, possibly *var. violascens, Rost.* Still more nearly approaching *P. nephroideum* is Lister's *var. robustum* with densely calcareous sporangia on stout, erect stalks and with larger, more distinctly warted spores. All of these varieties agree in their rather pale violet-brown spores as contrasted with the dark purplish-brown spores of *P. nephroideum.* Evidently, however, this is a distinction in which the personal equation plays altogether too important a part. In many cases it is quite impossible for two observers to agree as to the placing of a certain form under one or the other of the two extremes mentioned above. Under these circumstances the only possible course is to recognize the two centres *P. nutans* and *P. nephroideum* and to arrange the inter-

mediate forms under whichever centre they seem to approach most nearly.

A form occurs rather abundantly in the neighborhood of Boulder, which differs considerably from normal *P. nutans* but which we include under that species. The sporangia are globose or sub-globose, clear gray with patches or lumps of pure white lime on the surface, and measure 0.4-0.5 mm. in diameter. They are erect on slender or stout, tapering, black stalks, devoid of lime. The capillitium consists of an abundance of very slender threads, with few and small or many and larger fusiform or rounded lime-knots. The spores measure 9-11 μ, are almost smooth or minutely warted and of a clear violet-brown or almost claret-color.

Another form is similar, but the sporangia are rather larger, measuring as high as 0.7 mm. in diameter. They are either sessile or possess short, furrowed stalks of a dirty yellowish color. The capillitium is more robust but the spores are identical with those of the form described above.

Both of these are certainly forms of *P. nutans* as understood by Lister, and are placed under his *var. robustum.* They have been collected at Fort Collins, (Bragg); Boulder, (Bethel and Sturgis); Ouray, (Bethel).

PHYSARUM NEPHROIDEUM, *Rost.* This name is adopted in place of the *P. compressum, A. & S.* of Lister's Monograph, for the reasons given by Macbride, ("Slime-Moulds", p. 40), which seem to the writer amply sufficient. The species, readily distinguished by its dark, purplish brown, usually rather spinulose spores, appears to be common throughout the State. It has been collected at Boulder, (Bethel & Sturgis); Grand Mesa, Ouray, Tolland, and Fort Collins, (Bethel). The Fort Collins gathering shows a remarkable approach to *Physarum nodulosum, Cke. & Balf.,* in the reddish-brown stalk, merging into the concolorous and persistent base of the sporangium, but the dark, spinulose spores leave no doubt as to its proper position.

PHYSARUM CINEREUM, *(Batsch) Pers.* Mr. Bethel finds this species ocurring abundantly on grass, leaves and fallen twigs at Boulder and Golden. All of the gatherings are typical in habit and in detail.

PHYSARUM CONTEXTUM, *Pers.* This species is recognizable at sight by its densely aggregated habit and pale yellow, calcareous sporangia, often encrusting or sheathing the fallen twigs, leaves and bits of bark on which it occurs. It is

reported from Glen Park, (Sturgis); Palmer Lake and Golden, (Bethel); Boulder, (Bethel & Sturgis).

PHYSARUM VERNUM, *Sommerf.* In September, 1906, Mr. Bethel collected near Denver a small quantity of a form bearing a marked resemblance to *Physarum cinereum.* The gray, isolated or gregarious sporangia (occasionally plasmodicarps) are very small (0.4-0.6 mm. diam.) and are sessile upon a dead herbaceous stem. The fragile, single sporangium-wall easily breaks away, exposing the persistent white capillitium and black spore-mass. The capillitium consists of very abundant small rounded lime-knots with delicate connecting threads. The spores measure 10-11 μ diam. and are very dark purplish-brown (a color which also faintly tinges the sporangium-wall), and distinctly spinulose.

Macbride lists three species to which this form is somewhat similar—*P. cinereum, P. plumbeum* and *P. atrum.* From *P. cinereum* it certainly differs in the color and sculpture of the spores, and since the former feature is apparently repeated in the other two species mentioned, the identity of the form under consideration with either of them is precluded, even if it were not for differences in other points and the very doubtful validity of both *P. plumbeum* and *P. atrum.*

Except for the smaller size and the generally globose form of the sporangia, the Denver gathering corresponds to a specimen of *P. vernum* in the writer's herbarium, collected in England and determined by Mr. Lister after an examination of Sommerfelt's type. Regarding this species Mr. Lister writes (Journ. of Botany, Vol. 35, p. 210, June 1897), "On the one hand it is allied to *Physarum cinereum,* which it resembles in the sessile plasmodiocarps as well as in the capillitium. On the other hand it is allied to *Physarum compressum (P. nephroideum)* in the dark spores. Before receiving Sommerfelt's type I had contemplated publishing an account of the form as a dark-spored variety of *Physarum cinereum,* which is normally characterized by its pale spores; it is satisfactory however, to be able to trace it to a species already named, for notwithstanding the intermediate place which it holds between its two companions, rendering some gatherings difficult to determine, yet the main characters are constant."

This species has not been before reported from America and is represented by the single gathering referred to.

PHYSARUM DIDERMA, *Rost.* A peculiar form of this species occurs at Boulder and has been collected on two different occasions by Mr. Bethel and the writer. It consists almost entirely of rather long sinuous plasmodiocarps resembling *Physarum sinuosum, (Bull.) Weinm.* These, however, are not laterally compressed as in that species, nor do they split open along the upper edge. The inner wall of the sporangia shows the purplish tint characteristic of *P. Diderma* and the spores are dark purplish-brown in color, strongly spinulose on one side and measure 9-10.2 μ diam. The spores of *P. sinuosum* are paler, smaller and less coarsely but more evenly warted. Undoubtedly, however, the two species are very closely allied.

PHYSARUM SINUOSUM, *(Bull.) Weinm.* This common species occurs abundantly throughout Colorado. Specimens are before us from Buena Vista, Golden, Tolland, Boulder, and Palmer Lake, all collected by Mr. Bethel. The compressed sporangia, the outer wall splitting irregularly not rolling back from the persistent inner wall, the character of the spores, and the more regular rod-like capillitium with branching rather than rounded lime-knots, are features which serve to distinguish this species from the preceding one.

PHYSARUM DIDERMOIDES, *(Ach.) Rost.* The typical form of this species, with ovoid or cylindrical sporangia supported on white or yellowish membranous stalks, has not been reported from Colorado.

A specimen has been received from Boulder, (Bragg) showing small, crowded, spherical and sessile sporangia, somewhat resembling *Physarum cinereum.* The sporangium wall is, however, double and the spores are dark purplish-brown, spinulose, and measure 11.7-12.8 μ in diameter. In these features the gathering accords perfectly with *P. didermoides.* The shape of the sporangia in that species is a very variable character.

PHYSARUM TESTACEUM, *n. s.* In August, 1905, Mr. Bethel collected at Ouray, Colo., a peculiar *Physarum,* identical with a number of forms in the writer's collection which had been placed provisionally under the name *Physarum didermoides, var. lividum, (Rost.) List.,* (Jour. of Bot., May, 1898, p. 1.). Specimens of this gathering were sent to Mr. Lister and were confirmed by him, with the suggestion, however, that the variety showed so many points of difference from typical *P. didermoides* that it might well be considered

worthy of specific rank. The Ouray specimens may be described as follows:

Plasmodium? Sporangia subglobose, closely gregarious, or clustered and polygonal from mutual compression, 0.7 mm. diam., sessile. Sporangium-wall usually double; the outer white, smooth or wrinkled, delicate and shell-like; the inner membranous, colorless. Capillitium of numerous large or small, branching, angular, white lime-knots, connected by delicate, hyaline threads. Spores dark violet-brown, spinulose, but distinctly darker and more strongly spinulose on one side; 8-10.2 *μ diam. On bark of Abies concolor;* Ouray, Colo., leg. Bethel, Aug, 1905.

Except in the purer white of the sporangia, this species has a certain resemblance to *Badhamia panicea.* The plasmoduim was not seen but Lister *(l. c.)* gives the color as white. From *P. didermoides,* the form under consideration differs in the shape of the sporangia, the absence of a stalk, the usually shell-like double wall, the larger angular lime-knots, and the unequal thickness of the spore-wall. In the last-named feature it differs *(teste* Lister *in litt.)* from *P. lividum, Rost.,* in which the spores are equally dark and spinulose all over. The sporangium-wall is usually double, but the two layers may be so closely united as to be inseparable.

In the writer's collection is a specimen collected at Arlington, Mass., showing a single sporangium-wall less densely charged with lime, but agreeing in every other respect with the Ouray gathering.

Under the name *P. testaceum* the writer also includes a specimen received from Mr. A. P. Morgan of Preston, Ohio, marked *Physarum concinnum, B. & C.,* and the *"Physarum Diderma, Rost."* of Macbride's North American Slime-Moulds. These two specimens consist of closely aggregated groups of sporangia with white, densely calcareous, outer walls. As pointed out by Lister (Journ. of Bot., June 1897, p. 212), the name *Diderma concinnum, B & C.* refers to *Chondrioderma radiatum, (L.) Rost.* Macbride's *P. Diderma* appears to be a very different thing from Rostafinski's species as understood by Lister and from the specimens mentioned above (p. 18) under that name, with cylindrical sinuous plasmodiocarps. It is worth noting in this connection that a specimen received from Mr. N. L. Gardner of Berkeley, Cal., identical with *P. Diderma* as described above, was submitted by the writer to Prof. Macbride who confirmed the determination. If such specimens represent the true *P.*

Diderma, as Lister believes, it is difficult to include under that name the form described by Macbride. Finally, a number of specimens of *P. didermoides, var. lividum*, received from Mr. Lister, show the same divergences from *P. didermoides*, as do the American gatherings, and these specimens, as well as Morgan's *P. concinnum, (B. & C.)* and Macbride's *P. Diderma, Rost*, are therefore included under the name *Physarum testaceum, Sturgis*. Whether or not that name will stand depends on the stability of the spore-characters. Should future gatherings show that the unequal thickness of the spore-wall is a varying character and that in other respects *P. testaceum* approaches *P. lividum* too closely to be always distinguishable from it, the latter name must stand. But in any case, it seems fairly certain that this form can not be regarded as a variety of *P. didermoides*.

PHYSARUM PALLIDUM, *(B. & C.) List.* This rare but very characteristic species is represented by a single gathering obtained by Mr. Bethel at Tolland in October, 1906.

The name is based on two American specimens, one in the Kew Collection, from South Carolina, marked *Diderma pallidum, B. & C.;* the other in the British Museum Collection from Ravenel under the same name, (Lister in Journ. of Bot., April 1898, p. 5.). It is also the same *(teste* Lister, l. c., p. 10) as a specimen collected in Java by Raciborski and named by him *Physarum bogoriense, n. s.* Technically the latter name should be regarded as valid, since no description of their species was ever published by Berkeley and Curtis. But inasmuch as Berkeley *(Grevillea,* II. p. 52) refers to the specimen in the Kew Collection under the name *Diderma pallidum,* it seems advisable to retain that name. The species is related to *Physarum sinuosum* which it resembles in the shape of the plasmodiocarps and the manner of dehiscence. The outer wall, however, is smooth, of a brownish or tawny color, densely charged on its inner surface with white lime, and of a somewhat cartilaginous texture. The capillitium consists of numerous small, rounded, white lime-knots connected by long delicate threads. The spores are clear violet-brown in color, minutely spinulose, and measure 8-9 μ in diameter.

Inasmuch as *P. pallidum* has heretofore been reported only from Pennsylvania, the Southern States and the tropics, it is especially interesting to note its occurrence at high altitudes in Colorado.

PHYSARUM LATERITIUM, *(Berk. & Br.) Rost.* This species occurs only once in our Colorado gatherings, having been collected at Boulder by Mr. Bethel and the writer. The specimen resembles the descriptions of *Physarum rubiginosum, Fr.* in the elongated branching capillitial knots, but the single sporangium-wall heavily encrusted with brilliant orange-red deposits of lime, and the uniformly sessile habit, lead to its reference to the species quoted. It is the same as *P. inaequale, Pk.*, differing from typical specimens of that species only in the character of the lime-knots. A specimen received from the late Dr. G. A. Rex and compared by him with Peck's type shows rounded lime-knots, yellow, with red centres. In other specimens this bi-coloration is much less pronounced and the lime-knots are angular and branching. Macbride fails to see this feature in any of the specimens examined by him. The Boulder specimen shows a darker color in the centre of the lime-knots but it is apparently due merely to the greater density of the central portions of the knots, and not to the presence of amorphous plasmodic matter as in the case of the type-specimen of *P. inaequale,* (Cf. Sturgis, Trans. Conn. Acad. of Arts & Sc., Vol. x, p. 468). The double coloration therefore, can hardly be considered as a diagnostic feature.

PHYSARUM AURISCALPIUM, *Cke.* This species has been collected in small quantities at Palmer Lake and in the San Juan Mts., (Bethel); at Boulder, (Bethel & Sturgis); and near Colorado Springs, (Sturgis). Though varying much in habit, from long-stalked to sessile forms, it maintains its distinctive characters—the globose yellow sporangia; stalks, when present, brownish and translucent; capillitium of many branching yellow lime-knots; spores violet-brown, minutely warted.

PHYSARUM BERKELEYI, *Rost.* A gathering made near Colorado Springs in September, 1906 has been placed here, though it might, with almost equal propriety, be included under the preceding species. It is distinguished by the uniformly stipitate habit, the longer stalks, and the less abundant lime of the capillitium. (Cf. Lister, Journ. of Bot., April, 1898, p. 3.)

PHYSARUM NEWTONI, *Macbr.* This exquisite species, "easily recognized by its almost sessile, rose-purple, generally umbilicate sporangium," is described by Macbride (N. A. Slime Moulds, p. 37) from a single gathering collected in

Colorado by Prof. Newton. It has not been met with by the writer.

PHYSARUM CITRINUM, *Shumacher.* This species is reported from Colorado by Prof. Macbride *in litt.* Among the yellow, stipitate species of *Physarum* it is distinguished by its yellow stalk, charged throughout with lime, the yellow lime-knots of the capillitium, and the presence of a columella.

PHYSARUM COMPACTUM, *(Wing.) List.* The writer has not met with this species, but it is included in Prof. Macbride's MS. list of Colorado *Myxomycetes* referred to above

FULIGO, *Haller.*

FULIGO SEPTICA, *(L.) Gmel.* Common everywhere. Specimens, varying in color from pale yellow to brick-red and brown, are present from Arrowhead, Ouray, Pagosa, the South Platte, Tolland, Boulder, Golden and Palmer Lake, all collected by Mr. Bethel or the writer. The large size of the æthalia, the yellowish lime-knots, and the rather small, nearly smooth spores are characteristic features. Prof. Macbride writes *(in litt.)*, "A Colorado variety occurs with somewhat larger spores, 12-13 μ." This may referable to the following species. The specimens are difficult to preserve owing to the attacks of a small beetle of the genus *Enicmus.* Bisulphide of carbon has been found useful in reducing the damage done by this pest.

FULIGO ELLIPSOSPORA, *(Rost.) List.* To this species has been referred a single specimen collected by Mr. Bethel at Tolland. The pure white color of the large, much-weathered æthalium and of the capillitial knots, and the rather pale, violet-brown, minutely warted and usually oval spores, distinguish it from *F. septica.* The spores measure 13 x 11 μ.

CIENKOWSKIA, *Rostafinski.*

CIENKOWSKIA RETICULATA, *(Alb. & Schw.) Rost.* A remarkable species easily recognized by the creeping and amastomosing plasmodiocarps of a brownish color, marked with dull scarlet bosses. Two small specimens were collected by Mr. Bethel and the writer, at Boulder, in September, 1906.

CRATERIUM, *Trentepohl.*

CRATERIUM LEUCOCEPHALUM, *(Pers.)Ditm.* Widely distributed throughout the State. Reported from Boulder,

(Bethel & Sturgis); Tolland and Golden, (Bethel); Colorado Springs, (Sturgis). At Boulder it occurred in extraordinary abundance on dead leaves and twigs, in bramble-patches, often in company with *Didymium nigripes, Fr.*

CRATERIUM MINUTUM *(Leers) Fr.* This species was found in abundance at Boulder by Mr. Bethel and the writer in September, 1906, but has not been reported from elsewhere in the State. General usage would seem to warrant the adoption of the name *C. pedunculatum, Trent.*, for this species, but Fries (Syst. Myc. III, p. 151) writes *"Peziza minuta, Leers;* descriptio eximia," and though he adds "Medium inter *Cr. peduncul.* et *Cr. leucocephalum,* verum abunde distinctum," yet his own description of *C.minutum* leaves no room to doubt that it is the same as the *C. pedunculatum* of Trentepohl. Where the law of priority is so plainly justified, it seems necessary to follow it.

LEOCARPUS, *Link.*

LEOCARPUS FRAGILIS, *(Dicks.) Rost.* Specimens of this striking species are present from Tolland and Palmer Lake, (Bethel); Glen Park and Colorado Springs, (Sturgis). The large, rich brown, highly polished sporangia can hardly be taken for anything else.

LEOCARPUS FULVUS, *Macbr.* This very rare species is represented by a single gathering made by Mr. Bethel in June 1896, "on living willow growing in snow at 11,000 ft. alt. Loveland Pass, Colo." It is well developed and presents the following characters.

Sporangia globose or turbinate, 0.8-1.2 mm. diam., gregarious or scattered, pale yellow or tawny, sessile or stalked. Stalks, when present, pale yellow, membranous, being merely extensions of the membranous hypothallus. Wall cartilaginous with scanty deposits of minute yellow lime-granules. Capillitium a dense mass of very delicate hyaline threads, expanded at the angles, the expansions occasionally filled with yellow lime. Spores dark purplish brown, spinulose, 11-12.5 μ diam. The double wall mentioned by Macbride (N. A. Slime-Moulds, p. 82) is not apparent in our specimen; otherwise it agrees perfectly with the description. Another specimen from Mr. Bethel marked *"Leocarpus. On leaves of Abies lasiocarpa, under willows at timber line, Yankee Doodle Lake, Sept.* '06," may be this species, but it is so immature that the characters can not be made

out with certainty. The gross appearance is that of *Leocarpus fulvus.*

In this connection much interest attaches to two specimens in the writer's collection marked *Physarum albescens, Phillips,* and received some years ago from Mr. Harold Wingate of Philadelphia. One is from the Rex herbarium and was collected in Iowa by Mr. E. W. D. Holway. The other is from Ellis's herbarium and was collected by Mr. Langlois in Louisiana. The Louisiana specimen agrees in every detail with Macbride's *Leocarpus fulvus.* The Iowa specimen is the same, except that the sporangia are more uniformly sessile and the spores are pale violet-brown, minutely warted, and measure only 8.6-9 μ in diameter. The capillitium, too, shows more abundant lime-knots. There can be no doubt, however, that they are both the same thing and that they are identical with Macbride's *Leocarpus.* If the origin of the name *Physarum albescens, Phill.* could be traced, it would take precedence of the name given by Macbride, but no mention of it can be found in the literature of the subject. So far, therefore, as the literature is concerned, it is a *nomen nudum,* but the fact remains that there are specimens bearing the name *Physarum albescens, Phill.* We leave it to experts to decide which name should be adopted, but we mark the Iowa and Louisiana specimens *Leocarpus fulvus, Macbr.*

DIDERMA, *Persoon.*

DIDERMA STELLARE, *(Schrad.) Pers.* This species occurs abundantly on decayed cottonwood. Specimens have been received from Tolland and Palmer Lake, (Bethel); Glen Park and Colorado Springs, (Sturgis); Boulder, (Bethel & Sturgis). The short-stipitate, rarely sessile sporangia, ashen or pale brown in color and marked with paler lines of dehiscence; and the stout, usually pale stalk, serve to mark the species. As to the specific name, *radiatum* seems to be properly excluded (cf. Macbride, N. A. Slime-Moulds, p. 105). Schrader's description and figures of *Didymium stellare* may, without too severe a strain upon the imagination, be taken to refer to the species under consideration, and that name is therefore adopted here.

DIDERMA SPUMARIOIDES, *Fr.* This species is fairly common, forming an effused whitish crust on dead leaves, grasses, &c. The white plasmodium often creeps up on living grass-stems and forms sporangia at a height of several inches above the ground.

Reported from Boulder, and the San Juan Mts., (Bethel), and from Glen Park, (Sturgis).

DIDERMA MICHELII, *(Lib.)* A rare species reported but once from Colorado. It was collected by Mr. Bethel at Aurora in August, 1906. The discoid sporangia with pure white fragile outer wall and flattened or almost obsolete columella of a pinkish brown color are its distinguishing characteristics. The Aurora gathering shows usually sessile sporangia; here and there however, occur sporangia with short, stout, yellowish stalks.

The synonomy of the species is perplexing. Bulliard (Hist. des Champ, de Fr., I, p. 93, Pl. 446, fig. 1) describes and figures *Reticularia hemisphærica,* but gives the color of the sporangia as "brun-noiratre." Sowerby (English Fungi, Pl. 12) gives an admirable figure of our species under the name *Reticularia hemisphærica, Bull.,* but Rostafinski, giving the synonomy of his *Chondrioderma Michelii,* writes *"Reticularia hemisphærica, Sow. non Bull.,"* and refers Bulliards figures to species of *Didymium* (Mon. pp. 172 and 386). Libert issued specimens of *Didymium Michelii* and Corda (Icon. Fung. v. p. 57, Taf. III, fig. 33) describes what is unquestionably the form under consideration and refers to Libert's specimens. The validity of the specific name *Michelii* therefore, rests upon actual specimens as well as upon excellent descriptions and figures, while a considerable degree of doubt exists regarding the form described by Bulliard under the specific name *hemisphærica.*

DIDERMA TREVELYANI, *(Grev.) Fr.* This species is reported from Colorado by Macbride, and it occurs in our collection, specimens having been found at Golden and Boulder by Mr. Bethel. It is characterized by sub-ovoid sporangia of a yellowish brown color marked by pale lines of dehriscence extending from the apex to the base. At maturity the wall splits open in revolute lobes exposing the inner surface which is white from the prescence of coarse crystalline masses of lime. The stalks are short and brown, and there is no columella.

DIDERMA TESTACEUM, *(Schrad.) Pers.* A single small gathering made by the writer near Colorado Springs in September, 1906, has been somewhat doubtfully refered to this common species. The sessile sporangia are more depressed than usual and are pure white instead of flesh-colored, thus resembling sessile forms of *D. Michelii,* but on the whole it seems referable to the species quoted.

DIDERMA GLOBOSUM, *Pers.* This species was found in a rather immature condition at Boulder by Mr. Bethel and the writer. The poorly developed, dirty-white sporangia are seated upon a densely calcareous, concolorous hypothallus. The dark spores measure 12.5 μ in diameter.

Prof. Macbride lists *Diderma crustaceum, Pk.* from Colorado. In the writer's opinion this is the same as *Diderma globosum.* (See Trans. Conn. Acad. Arts, Sc. Vol. x, p. 473).

DIDERMA NIVEUM, *(Rost.) Macbr.* This rare species is represented by a single specimen collected by Mr. Bethel, submitted to Prof. Macbride and marked by him *"Diderma Lyallii, Mass.,* Colo. '02." The specimen consists of a cluster of 40-50 large subglobose sporangia sessile upon or rising on delicate whitish stalks from a membranous, rather scanty hypothallus. The sporangium-wall is white and shows a yellowish inner wall. The columella is pale brown and prominent. The capillitium consists of coarse brown threads with paler tips. The spores are very dark and spinulose, and measure 12.5-14.5 μ diam.

Under date of Oct. 30th, 1905 Mr. Lister writes, regarding a collection of Myxomycetes gathered in Switzerland by Miss Lister. "Also *Chondrioderma Lyallii, Mass.* in interesting variety, showing that it is the same species as Rostafinski's *Chondrioderma niveum.* It was found in several places at the Bel Alp close to the melting snow; some of it exactly matching with the type of *C. niveum* in the Strassburg collection marked *'neben der schmeltzenden Schnee'*—some with densely calcareous sporangium-wall, and others *black* without lime."

DIDERMA SAUTERI, *(Rost.) Macbr.* Prof. Macbride records this species as occurring in Colorado. It is not included in our collection.

DIACHAEA, *Fries.*

DIACHAEA LEUCOPODA, *(Bull.) Fr.* Very abundant locally at Boulder, covering dead leaves over a large area, in shady thickets.

DIDYMIUM, *Schrader.*

DIDYMIUM FARINACEUM, *Schrad.* This and the next species are mong the most common of Colorado *Myxomycetes. D. farinaceum* is readily recognized by its crystalline wall, and its dark brown stalk and columella.

Specimens are before us from Colorado Springs, (Sturgis); Boulder, (Bethel & Sturgis); and Tolland, (Bethel).

DIDYMIUM SQUAMULOSUM, *(Alb. & Schw.) Fr.* Abundant throughout the State in favorable situations; Boulder, Denver, Fort Collins, Aurora, Tolland, (Bethel); Colorado Springs, (Sturgis). The stipitate forms resemble *D. farinaceum,* but differ in the snow-white stalk and columella. Sessile forms with globose sporangia and very dark spores measuring 10.5-12 μ are frequently met with. The Aurora specimen is of this type and closely approaches *D. crustaceum.*

DIDYMIUM SQUAMULOSUM, *var.* CLAVIFORME, *n. var. Sporangia stipitate, disc-shaped,* 0.4-0.5 *mm. diam.,* 0.2 *mm. or less thick, snow-white, rugose, deeply umbilicate and yellowish beneath, umbilicate above. Stalk* 0.3-0.5 *mm. long, white, furrowed. Columella hemispherical or depressed, white. Capillitium of delicate, flexuous, hyaline threads, with occasional small fusiform expansions. Spores* 9-12 μ *diam., rather dark violet-brown, irregularly warted.*

On dry fruits of Echinocystis lobata. Bethel leg., Denver, Colo., September, 1906.

This form resembles a minute *Didymium Clavus,* from which however, it is distinguished by the presence of a columella and the character of the spores. From all normal forms of *D. squamlosum* it differs in the shape of the sporangia, while agreeing with that species in all other respects. The spores are peculiar in their marking, the minute warts being here and there collected in small clusters as in *Comatricha typhoides.*

DIDYMIUM ANELLUS. *Morg.* ("The Myxomycetes of the Miami Valley, Ohio," p. 64, 1894). This extremely delicate and characteristic species was found by Mr. Bethel at Boulder in September 1906, growing upon dead leaves. A little later the present writer collected it near Colorado Springs, on the inner bark of decayed cottonwood logs, in company with *Perichæna corticalis, (Batsch) Rost.*

Morgan describes the species perfectly, as follows:

"Plasmodiocarp in small rings or links, then confluent and elongated, irregularly connected together, bent and flexuous, resting on a thin venulose hypothallus; the wall firm, dark-colored, with a thin layer of stellate crystals of lime, irregularly ruptured. Columella merely a thin layer of brown scales. Capillitium of slender, dark-colored threads which

extend from base to wall, more or less branched, and combined into a loose net. Spores globose, very minutely warted, violaceous, 8-9 mic. in diameter."

The Boulder specimen corresponds in every respect with this description. Those from Colorado Springs are in the form of extremely thin grayish crusts, the plasmodiocarps being only indicated by depressions in the surface. The capillitium threads are straighter and coarser than in the Boulder gathering, and the spores are darker and larger, measuring 12-13 μ diam. Occasionally distinct sporangia occur in the Boulder gathering, but they are always sessile, much flattened and often umbilicate above or even annulate.

Lister (Journ. of Bot., June, 1897, p. 214 and April, 1899, p. 5) described this form under the name *Didymium effusum, Link, var. tenue, List.* It seems however, to be abundantly worthy of specific rank and Morgan's name takes precedence.

DIDYMIUM NIGRIPES, *(Link) Fr.* A single small and poorly developed specimen collected by the writer near Colorado Springs represents the typical form of this species, with dark brown stalk and columella.

The common form in Colorado is the *var. eximium, (Pk.) List., (Didymium eximium, Pk).* This has been collected in quantity at Colorado Springs, (Bethel & Sturgis), and at Bouder, (Bethel). It shows irregularly globose sporangia of a yellowish gray color, a large pale brown columella, and capillitium of pale, branching and anastomosing threads, expanded toward the surface of the columella and showing here and there fusiform expansions with yellowish contents. The spores average 9 μ in diameter. The writer's reasons for following Lister in making this form a variety of *D. nigripes,* have been sufficiently stated elsewhere. (Trans. Conn. Acad. Arts & Sc., Vol. x, p. 478 e. s.)

DIDYMIUM DIFFORME, *(Pers.) Duby.* This species is readily distinguished by its much appressed sporangia or plasmodiocarps, with smooth, fragile, white walls, the lime being in the form of crystalline masses, not in spherical granules as in the genus *Diderma.* It is represented in our collection by specimens gathered at Denver by Mr. Bethel, on dead leaves and twigs and on bits of glass.

DIDYMIUM CLAVUS, *(Alb. & Schw.) Rab.* Listed by Macbride (in MS.) as a Colorado species. It is not represented in our collection.

SPUMARIA, *Persoon.*

SPUMARIA ALBA, *(Bull.) DC.* This occurs in abundance and in extraordinarily varied forms. At Boulder the normal form was found, with ragged æthalia forming on grass-stalks and on the stems of shrubby plants. At Pagosa Springs and again at Palmer Lake a form occurs in abundance in which the sporangia are less closely associated and are seated upon a dense white hypothallus forming a crust upon wood and only occasionally on twigs and grass-stems. But the most remarkable forms are represented by specimens gathered at Boulder and Denver by Mr. Bethel. At first sight they would unhesitatingly be placed under *Fuligo septica,* judging only by the habit and gross appearance. They occur uniformly on the bark of fallen logs, usually of cottonwood, and are in the form of massive æthalia often 4-5 cm. in diameter and 2-2.5 cm. in thickness, covered with a very thick crust of cream-white lime which is either spongy in appearance or smoother and pulverulent, as though the spongy crust had been rubbed down with the finger. Sometimes the spongy crust falls away in large flakes exposing the pulverulent layer beneath. In these cases the lime is in minute crystals combined into small masses. Again the æthalia are flatter and cake-like, covered with a dense white coating of lime but very solid in texture beneath, the sporangia being inextricably intertwined. Such specimens are usually found growing in company with the flat purplish athalia of *Fuligo ellipsospora,* often so intimately as to be partially superimposed. There is undoubtedly an extreme divergence in both appearance and structure between these massive forms and the effused forms collected at Pagosa Springs and elsewhere in which the separate sporangia occur in a single layer and are plainly distiguishable. The capillitium of the former also differs markedly from that of normal *S. alba* and the spores are smaller. On the whole it seems advisable to consider this as a well-marked variety, and it is so designated, as follows.

SPUMARIA ALBA, *var.* SOLIDA *n. var. Plasmodium milk-white. Aethalia massive, 4-5 cm. in diameter, 1-2.5 cm. thick, covered with a very thick spongy or pulverulent coating of cream-white lime; the lime usually in the form of small, crystalline masses. Capillitium scanty, of delicate, hyaline, anastomosing threads, with occasional fusiform expansions filled with dark matter. Spores, dark purplish*

brown, rather minutely spinulose, 8-11 μ diam. On the outer bark of fallen cottonwood logs. Denver, Boulder and Palmer Lake, (Bethel), May to September, 1906.

STEMONITIS, *Gleditsch.*

STEMONITIS FUSCA, *Roth.* We here place the common dusky or smoky-brown form, with more or less reticulated spores, so common in this country. Macbride ("Slime-Moulds," p. 115) characterizes this species as having spores "smooth or more or less warted, but not reticulate," and applies the name *S. maxima, Schw.* to the common form with reticulate spores. The late Dr. Rex distributed specimens (Ell. & Ev. N. A. F. 2697) labelled *"Stemonitis maxima, Schw.,* Compared with the type in Herb. Schw." These have reticulated spores.*

There is no question therefore, about the spores of the Schweinitz species. Of Roth's species there is, so far as is known, no type in existence, and we have to fall back on Rostafinski. Macbride writes (l. c.) "Specimens identified by Rostafiinski in 1875 as *S. fusca* have the spores slightly warted when viewed under a Zeiss 1-12." What these specimens are we do not know, but in what we call *S. fusca* the reticulation shows much variation and it is very doubtful whether Rostafinski would have been able to distinguish between a punctate reticulation and a minute, even warting of the surface. Moreover according to Lister (Mon. p. 111) Rostafinski's specimens of *S. fusca* in the British Museum and the Strassburg Museum, have faintly reticulated spores. In correspondence with the writer Mr. Lister also says "There are more than 20 specimens marked *S. fusca* in the Kew and British Museum collections, examined by Rostafinski; all of these have reticulated spores." As noted above, it is highly improbable that Rostafinski would have been able, with the lenses at his command, to recognize a more or less faint and broken reticulation; in fact he describes the spores of his specimens as smooth when we now know that they are reticulated. When, in addition, a large number of specimens marked *S. fusca* and which were examined by Rostafinski, are found to have reticulated

* There is another specimen (No. 1119) in the same collection, labeled *Stemonitis fusca, Roth*, collected by Dr. Rex. This has spores showing a broken punctate reticulation. In the box containing this specimen there is, at least in the writer's set, a fine specimen of *Comatricha heterospora*, Rex. The non-identity of the two specimens was evidently overlooked by Dr. Rex.

spores, we are surely justified in placing specimens showing this character under the name *S. fusca.* What to do with the somewhat similar form, with smooth or faintly and evenly warted spores, is another question. Lister calls it *S. splendens, Rost.* It is rare in Europe, but occurs, commonly in this country.

In connection with normal *S. fusca,* mention should be made of certain specimens collected at Boulder by Mr. Bethel and the writer in October, 1906. They show small clusters of purplish or reddish brown sporangia, cylindrical, 2-3.5 mm. in height and very short-stalked, rising from a thin hypothallus. The capillitium shows an imperfect surface-net with many long free tips, especially toward the apex of the sporangium. The spores are rather pale reddish-brown and appear smooth; under a Leitz 1-12 however, a faint reticulation can be seen. They measure 8-9 μ in diameter. These specimens very closely resemble *Comatricha heterospora, Rex (C. typhoides, var. heterospora* of Lister's Monograph), their only distinguishing feature being the large spores. They belong undoubtedly to Lister's *var. rufescens* of *Stemontis fusca,* and serve to show how closely connected are the genera *Stemonitis* and *Comatricha.*

S. fusca, Roth, as defined above, occurs in our Colorado collection from Tolland, (Bethel); Boulder, (Bethel & Sturgis,) and Glen Park, (Sturgis).

STEMONITIS SPLENDENS, *Rost.* This species closely resembles the preceding, but is distinguished from it by the nearly smooth or minutely and evenly warted spores. It is frequently found on the edges of board-walks and on railway ties. It has been found at Denver, Palmer Lake, Boulder and Ouray, (Bethel). Specimens from Palmer Lake and Boulder show Lister's *var. flaccida,* with adherent sporangia, capillitium without a surface-net and with remnants of the sporangium-wall in the shape of pale brown flakes. The *var. confluens* has been found at Denver, though in poor condition.

STEMONITIS HERBATICA, *Pk.* This name rather represents a convenient centre, around which to group forms not easily referable elsewhere, than a species with definite limits. In a previous paper (Trans. Conn. Acad. of Arts and Sc., Vol. x, p. 482) the writer, after examining Peck's type of *S. herbatica,* said "I cannot with any certainty distinguish between *S. herbatica, Pk.* and *S. ferruginea, Ehr.*" This statement still expresses the writer's opinion. Nevertheless,

though the two species are connected by many intergrading forms, it seems convenient to make a distinction between them as centres. In a general way what we call *S. herbatica* is distinguished by its color, neither as dark and purplish as *S. fusca* and *S. maxima* nor as ferruginous as *S. ferruginea.* The surface-net is composed of small meshes but they are neither as small nor as pale as in *S. ferruginea,* and the spores (7.5-8 μ diam.) are rather larger and darker than those of *S. ferruginea.* Specimens are before us from Colorado Springs, (Shantz); Tolland, the San Juan Mts., Glen Park and Boulder, (Bethel).

STEMONITIS FERRUGINEA, *Ehr.?* In a recent paper (Abhandl. d. Bot. Vereins d. Prov. Brandenburg, XLV, p. 164) Dr. E. Jahn publishes the results of his studies of the ferruginous species of *Stemonitis.* Two forms are recognized, distinguished by the color of the plasmodium. One has a *white* plasmoduim and includes *S. ferruginea, Ehr., S. microspora, List.,* and *S. Smithii, Macbr.* The other has a *yellow* plasmodium and to this form Jahn gives the name *S. flavogenita.* It includes the form called by Fries *S. ferruginea,* since that form had *(teste* Fries) a yellow plasmodium. If we accept Jahn's conclusions it is evidently necessary to know the color of the plasmodium before we can decide with certainty whether our common ferruginous species is really, as it has always been called, *S. ferruginea, Ehr. (S. Smithii, Macbr.)* or whether we have to do with Jahn's *S. flavogenita.* The size of the spores does however, furnish another, though not always very reliable, clue to the species, those of *S. ferruginea* being somewhat the smaller. Mr. Lister, who has made a careful comparative study of these two forms and the related *S. herbatica Pk.* suggests *(in litt.)* the following key.

	Spores	Plasmodium	Surface-net
S. ferruginea, Ehr. *syn. S. microspora, List.* *S. Smithii, Macbr.*	4-5 μ rusty	White or white with a green tinge	Usually firm and close
S. flavogenita, Jahn. *syn. S. ferruginea, Fr.*	6-8 μ rusty	Translucent Citron-yellow	Delicate, not very close
S. herbatica, Pk.	6.5-8 μ pale purplish gray.	White, cream-color, lemon yellow	Usually firm

Whether future investigations will justify the above scheme, remains to be seen. The whole subject is a confused and difficult one. We have here placed under the

name *S. ferruginea* specimens from Boulder, (Bethel & Sturgis); Colorado Springs, (Sturgis); Tolland and the San Juan Mts., (Bethel). They are all ferruginous in color, but the size of the spores varies. In some they measure 4.5 μ diam., in others as high as 6.5 μ. There is also great variation in stature, from 4 mm. to 1.5 cm. If *S. Smithii, Macbr.* is recognized as a species distinct from *S. ferruginea, Ehr.*, the larger forms might be placed under the former name.

COMATRICHA, *Preuss.*

COMATRICHIA NIGRA, *(Pers.) Schroet.* The common form of this species—the only one recognized by Macbride as rightly belonging under this name—occurs abundantly throughout Colorado. It is usually found on coniferous wood and is easily recognized by its more or less globose or ovoid sporangia erect on long delicate stalks. Mr. Bethel has collected it in abundance at Palmer Lake, Tolland, Denver, Ouray, and Boulder. It occurs also in the neighborhood of Colorado Springs, (Sturgis). Specimens gathered on Pike's Peak by Mr. Shantz show exceptionally long stalks, and sporangia larger and darker in color than usual.

var. SUKSDORFII, *Ell. & Ev. (ut. sp.).* This form is apparently common. Our collection includes specimens from Tolland, Arrowhead, Granby and Yankee Doodle Lake, all gathered by Mr. Bethel. In its typical form it bears little resemblance to the species, showing a densely gregarious habit, elongate-ovoid sporangia almost black in color, very short stalks, dense and dark capillitium, and dark spores 10-11 μ in diameter. Other gatherings, however, show the sporangia scattered, more or less globose, mounted on stalks equalling or exceeding the height of the sporangia, and with large spores (10-13 μ diam.). Such specimens vary in color from grayish to almost black, in the latter case bearing a very close outward resemblance to *Lamprodcrma* or even *Enerthenema.* Intermingled with these are often found forms quite indistinguishable from typical *C. nigra,* so that the gatherings show every gradation between that species and *C. Suksdorfii.* With only the two extremes of this series in mind, Macbride accords specific rank to both. Lister, on the other hand, emphasizing the connecting links in the series, refuses even varietal rank to *C. Suksdorfii.* In the writer's opinion, convenience seems to warrant some sort of distinction between the two extremes of such a series, while

not losing sight of their manifest relationship. The name *Suksdorfii* is therefore given varietal rank.

var. AEQUALIS, *Pk., (ut sp.).* As in the preceding case, Macbride retains this name as applying to a distinct species, while Lister merges it with *C. nigra.* Only one specimen has been collected in Colorado. It was found by Mr. Bethel at Boulder. Most of the sporangia are of the typical cylindrical shape and large size, but they vary much in size, the smaller ones being identical with robust forms of *C. nigra.* The examination of a large series of specimens, including Peck's type, leads the writer to regard *C. aequalis* as merely a well-marked variety of *C. nigra.*

COMATRICHIA LAXA, *Rost.* Except for its lax and rather open capillitium, this species closely resembles small, erect forms of *C. nigra.* Mr. Bethel has collected it at Boulder, Tolland, Aurora and Mammoth.

COMATRICHA TYPHINA *(Wigg.) Rost.* Among the cylindrical forms of *Comatricha,* this species is readily recognized by its small, pale spores, almost smooth except for a few small clusters of minute papillæ. Occasionally these clusters or warts are connected by a delicate broken reticulation, and in rare cases the reticulation alone is present with no sign of the warts. To specimens exhibiting such reticulated spores Rex gave the varietal name *heterospora.*

Both the species itself and its variety (the latter predominating) have been collected at Glen Park, (Sturgis); Boulder, (Bethel & Sturgis); Palmer Lake, Tolland, Ouray, and the San Juan Mts., (Bethel).

COMATRICHIA IRREGULARIS, Rex. This species, easily mistakable for a *Stemonitis,* occurred abundantly in August, 1906, at Boulder on fallen logs of cottonwood. The densely gregarious, purplish black sporangia are characteristic. Specimens have also been receivel from Fort Collins.

COMATRICHA PERSOONII, *Rost.* A single gathering of this rather uncommon species was made by Mr. Bethel in the San Juan Mts., in July, '97. The small, reddish-brown, cylindrical or ovoid sporangia were found in some abundance on dead leaves.

ENERTHENEMA, *Bowman.*

ENERTHENEMA PAPILLATA, *(Pers.) Rost.* Occurs rather rarely and in small quantity. Specimens are present from near Colorado Springs, (Shantz, Sturgis); Boulder and Tolland, (Bethel).

LAMPRODERMA, *Rostafinski.*

LAMPRODERMA VIOLACEUM, *(Fr.) Rost.* Only two specimens of this species occur in our collection, one from Ouray, (Bethel), the other, also collected by Mr. Bethel, but only labelled "Colorado, '02." They are both very scanty. The species is undoubtedly rare.

LAMPRODERMA SAUTERI, *Rost.* By Lister this is regarded as a variety of the preceding species. Macbride regards it as specifically distinct, and with this view the writer is inclined to agree. The persistent base of the sporangium-wall, the more regular capillitium with very delicate hyaline tips, and especially the larger, rougher spores, seem to differentiate it from *L. violaceum.* We have but one specimen from Colorado. This was collected by Mr. Bethel in 1902, but the exact locality is not noted.

LINDBLADIA, *Fries.*

LINDBLADIA EFFUSA, *(Ehr.) Rost.* Mr. Bethel has collected this species twice, at Palmer Lake and at Golden. Both specimens are in the form of an effused one or two-layered crust of delicate, closely aggregated sessile sporangia.

CRIBRARIA, *Persoon.*

CRIBRARIA ARGILLACEA, *Pers.* Fairly common. Specimens are present from Glen Park, (Sturgis); Boulder, (Bethel & Sturgis); Tolland, (Bethel). Some of the Boulder specimens are of peculiar interest as exhibiting the close relationship existing between this species and the *var. simplex* of *Lindbladia effusa;* indeed the two genera intermingle at this common point.

CRIBRARIA MINUTISSIMA, *Schw.* This species is usually found abundantly when once seen, but its mintue size renders it liable to be overlooked. It has been collected in the mountains near Colorado Springs, (Shantz and Sturgis); and at Boulder, (Bethel). It is probably very widely disseminated in mountainous regions.

CRIBRARIA MACROCARPA, *Schrad.* A single gathering of this species was made by the writer at Glen Park, in August, 1905.

CRIBRARIA AURANTIACA, *Schrad.* Found in small quantity by the writer at Glen Park, and by Mr. Shantz in the neighborhood of Colorado Springs.

CRIBRARIA INTRICATA, *Schrad.* In the MS. list of Colorado *Myxomycetes* referred to above, Prof. Macbride includes this species, under the name *C. dictydioides, Cke. & Balf.* In the present writer's opinion these two species are identical. This opinion was shared by the late Dr. Rex who wrote, *(in litt., Feb. 22nd, 1893), "C. intricata* and *C. dictydioides* are undoubtedly the same, the size or absence of the calyculus having no specific value." Lister (Mon. p. 144) places the latter as a variety of *C. intricata.*

CRIBRARIA ELEGANS, *B. & C.* Prof. Macbride also lists this species as a Colorado form. It is not included in our collection.

CRIBRARIA VIOLACEA, *Rex.* Probably rare, though liable to escape observation owing to its minute size and dark color. The writer obtained it in considerable quantity on the inner bark of cottonwood logs in a damp cañon near Colorado Springs, September, 1906.

DICTYDIUM, *Schrader.*

DICTYDIUM CANCELLATUM, *(Batsch) Macbr.* Common everywhere; Denver, Golden, Tolland, Arrowhead, on the South Platte and in the San Juan Mts., (Bethel); Colorado Springs, (Shantz); Manitou Park and Glen Park, (Sturgis). The specimens from Glen Park frequently show the abnormal form called by Rostafinski *Heterodictyon,* the sporangium-wall, especially in the upper part, showing an irregular net with large, angular nodes, closely resembling *Cribraria.* Below, the strong ribs connected by delicate parallel threads, are usually apparent. The spores too, are identical with those of *Dictydium.*

TUBULINA, *Persoon.*

TUBULINA CYLINDRICA, *(Bull.) Rost.* Collected in small quantities at Tolland and on the South Platte, (Bethel), and at Glen Park, (Sturgis). The synonomy of the species is so hopelessly confused and the earlier observers were so little able to distinguish between this and forms resembling it in outward appearance, that it seems permissible in this case to ignore rules of strict priority and to use the name selected by Rostafinski.

DICTYDIÆTHALIUM, *Rostafinski.*

DICTYDIÆTHALIUM PLUMBEUM, *(Schum.) Rost.* This peculiar species, with its extremely appressed æthalia, ap-

pears to be rather rare. Specimens are before us from Palmer Lake and Boulder, both collected by Mr. Bethel. One other specimen, also collected by Mr. Bethel, but with no locality other than "Colorado", shows a marked divergence from the normal form, in that the threads representing the angles of the contiguous sporangia are, in most cases, more or less connected by delicate cross-ribs. The normal form also occurs in the same specimen.

ENTERIDIUM, *Ehrenberg.*

ENTERIDIUM OLIVACEUM, *Ehr.* A single specimen of this rare species was collected by Mr. Bethel at Palmer Lake in June, 1901. It is in the form of a thin, effused æthalium, 3 cm. long and about 1.5 cm. wide. The clustered spores and the appressed form of the æthalium distinguish it from the following species.

ENTERIDIUM ROZEANUM, *Wing.* Our collection contains two specimens of this species, both collected by Mr. Bethel. One of these was collected at Boulder, and is in the form of a pulvinate æthalium, 3 cm. in diameter. The other bears merely the locality-label "Colorado, '02." It is a very large æthalium, 6 x 3 cm., and with a firm, brown, outer crust.

Prof. Macbride, (N. A. Slime Moulds, p. 151), substitutes for the specific name *Rozeanum,* the name *splendens* given to this species by Morgan, on the ground that the specimens on which Wingate based the specific name given by him "are no longer to be consulted." Mr. Wingate, a most accurate observer, satisfied himself that certain European specimens collected by Roze were identical with our American species of *Enteridium,* and named them *E. Rozeanum.* Inability to verify Wingate's conclusions should not invalidate the name which he gave.

RETICULARIA, *Bulliard.*

RETICULARIA LYCOPERDON, *Bull.* This species appears to be common throughout the State and often attains a very large size, four to five inches in diameter. It occurs frequently on decorticated portions of living trees and, with its silvery-white cortex, forms a very conspicuous object.

TRICHIA, *Haller.*

TRICHIA PERSIMILIS, *Karst.* This and the next following species are among the most conspicuous of the *Myxo-*

mycetes, owing to their abundant and closely crowded sporangia and their brilliant yellow color. *T. persimilis* is represented in our collection by specimens from the San Juan Mts., the South Platte and Ouray, (Bethel); and from Glen Park, (Sturgis).

TRICHIA AFFINIS, *DBy.* Hardly to be distinguished from the preceding species; indeed Macbride unites the two under the name *T. persimilis.* The somewhat paler, brighter color of the sporangia in *T. affinis* and the more complete reticulation of the spore-sculpture are fairly constant features and serve to differentiate it from *T. persimilis.* All of our specimens are from the San Juan Mts. and were collected by Mr. Bethel.

TRICHIA CONTORTA, *Rost.*

var. INCONSPICUA, *Rost.* Common on the inner bark of Box Elder, throughout the State. Specimens are before us from Colorado Springs, (Sturgis); Fort Collins, (Bragg); Silver Lake, (Watts); Ouray, Boulder and Denver, (Bethel). Mr. Bethel describes the plasmodium as "light pink turning yellow, then black."

Macbride follows Rostafinski in separating *T. inconspicua* from *T. contorta* on the ground of the less aggregate habit of the latter and its iregular capillitium; but considering the variability of these characters in all of the *Trichiaceæ,* they can not, in the present writer's opinion, be regarded as distinctive features. In the specimens before us sporangia are found in which the elaters are combined to form a net, and are irregular with bulbous expansions, the spirals inconspicuous or wanting; while in other cases, sometimes even in the same colony, the separate elaters are regularly cylindrical, and show distinct and even spirals and bulbous or evenly tapering tips. The character of the elaters seems dependent on the conditions during development rather than on any specific differences.

TRICHIA FALLAX, *Pers.* Very common and readily recognized by its usually gregarious habit and its stipitate, turbinate sporangia. Not infrequently the elaters are branched and even tend to form a net as in the genus *Hemitrichia.* Found in abundance at Colorado Springs and Glen Park, (Sturgis); Breckenridge, Tolland, Yankee Doodle Lake and in the San Juan Mts., (Bethel).

Macbride (N. A. Slime-Moulds, p. 218) writes *"T. decipiens (Pers.)"* This name antedates *"fallax"* by a year,

but the latter has the sanction of universal usage for a century and may well be allowed to stand.

TRICHIA VARIA, *(Pers.) Rost.* Common everywhere. Distinguished, among the species with papillate spores, by its elaters which are marked with only two loose spirals.

Colorado Springs, (Sturgis); Denver, Boulder and Ouray, (Bethel).

TRICHIA BOTRYTIS, *(Pers.)* This is apparently a rather rare species in Colorado. A single, scanty gathering was made by the writer near Colorado Springs in September, 1906. The scattered sporangia are turbinate and of a dark olivaceous brown color, marked with paler lines of dehiscence; the elaters and spores are dull yellow.

HEMITRICHIA, *Rostafinski.*

HEMITRICHIA CLAVATA, *(Pers.) Rost.* The specimens of this common species contained in our collection are remarkable for the varying features which they exhibit. Externally they are of the familiar type; stalked sporangia, turbinate in shape and of a bright, shining, yellow color. A large gathering made by the writer and Mr. Bethel at Boulder in August, 1906, exhibits marked peculiarities in its minute features. The threads of the capillitium, instead of being spirally banded as usual, are minutely and densely spinulose; the spores are also abnormal, being marked with a very delicate and incomplete reticulation. We should be inclined to make this gathering the basis of a new variety, were it not that other specimens from the same locality show only the one abnormality of reticulated spores. Others again, also with normal capillitium, show spores either smooth, or minutely warted, or reticulated, from sporangia otherwise normal and in the same colony.

Specimens are present from Boulder, (Bethel & Sturgis); Ouray, Tolland, and Arrowhead, (Bethel).

HEMITRICHIA OVATA, *(Pers.) Macbr.* This is the *H. Wigandii* of Rostafinski and of Lister's Monograph. Why the former abandoned the name given by Persoon is not apparent. (Cf. Macbride, N. A. Slime-Moulds, p. 203.). The species is not common, though fairly widely distributed. Specimens are present from Colorado Springs, (Sturgis, Shantz); Palmer Lake, Ouray and Yankee Doodle Lake, (Bethel).

ARCYRIA, *Hill.*

ARCYRIA INCARNATA, *Pers.* A fairly common species distinguished by its pinkish color and the loose attachment of the capillitium to the calyculus. Frequently the whole capillitium is blown or weathered away, leaving only the stalks and empty cup-like bases of the sporangia. The capillitium of this species exhibits a certain degree of variation in its markings. Normally the latter are in the form of cogs, transverse ridges or partial rings, but occasionally specimens occur in which the capillitium is minutely spinulose throughout.

Represented in our collection by specimens from Colorado Springs, (Sturgis, Shantz, Hall); Boulder and Tolland, (Bethel).

ARCYRIA PUNICEA, *Pers.* This is hardly more than a variety, and not a very well marked variety at that, of the preceding species, distinguished chiefly by the character of the capillitium which is more firmly attached to the calyculus and shows very few, if any, loose ends. Both species show a tendency to change color, after maturity, to dull brown. In Colorado *A. punicea* seems to be less common than *A. incarnata,* only scanty specimens being present from Colorado Springs, (Sturgis) and the San Juan Mts., (Bethel).

ARCYRIA POMIFORMIS, *(Leers.) Rost.* This minute species is easily recognized by its scattered, globose, dull yellow, shortly stipitate sporangia. It appears to be fairly common, but does not occur anywhere in great abundance and easily escapes notice. Mr. Lister considers it to be a variety of *A. cinerea, (Bull.) Pers. (A. albida, Pers.),* but the features in which it differs from that species are so constant that it seems advisable to regard them as specific even though there may be intermediate forms. Certainly our specimens from Colorado are as distinct as two species could well be, and show no connecting forms.

The present species is represented by specimens from Colorado Springs, (Shantz); Glen Park, (Sturgis); Boulder, (Bethel & Sturgis); Ouray and Denver, (Bethel).

ARCYRIA CINEREA, *(Bull.) Pers.* Specimens are before us from Glen Park, (Sturgis); Colorado Springs, (Shantz); Boulder, (Bethel). They are of the normal type, pale gray sporangia, cylindrical, short-stalked, and either scattered or gregarious.

ARCYRIA STIPATA, *(Schw.) List.* This species is evidently rare in Colorado for, notwithstanding its conspicuous habit, it is represented in our collection by only a single specimen collected by Mr. Bethel and marked "Colo. '02." The original carmine-brown color has faded to a dull brown, but the densely crowded, short-stalked sporangia, and the triangular capillitium-threads marked on the edges with blunt cogs and throughout with faint spirals, are characteristic features. Macbride refers this species to the genus *Hemitrichia* because of the spiral markings on the capillitium. It is certainly a connecting link between that genus and *Arcyria.*

ARCYRIA NUTANS, *(Bull.) Grev.* This is the commonest and most striking species of the genus in Colorado. Masses of the pale yellow capillitium occur everywhere, usually on fallen logs of *Pinus.* So evanescent is the connection between the capillitium and the short-stalked calyculus that they are seldom found united. Boulder, Ouray, Tolland, on the South Platte and in the San Juan Mts., (Bethel); Colorado Springs, (Shantz); Glen Park, (Sturgis).

ARCYRIA VITELLINA, *Phill.* A most beautiful species characterized by its pyriform or clavate sporangia of a clear, shining, chrome-yellow or dull olivaceous color, resembling *Hemitrichia clavata.* The threads of the abundant capillitium are normally elosely and minutely spinulose or warted; occasionally however, they show short transverse ridges in addition. Mr. Bethel has collected it in considerable abundance at Arrowhead, Tolland, and in the San Juan Mts.

Lister (Mon. p. 185) writes *"Arcyria versicolor, Phill."* and gives *A. vitellina* as a synonym. A strict interpretation of the law of priority compels the use of the latter name, since although Phillips described both forms on the same page of the same publication, the description of *A. vitellina* precedes the other.

PERICHAENA, *Fries.*

PERICHAENA DEPRESSA, *Lib.* Occurs commonly on the inner bark of Cottonwood and Willows in damp situations, but liable to be overlooked by reason of its much depressed sporangia and dull purplish brown or almost black color. After the falling away of the lid-like upper portion of the sporangia, however, the bright yellow mass of spores and capillitium is striking.

Collected in abundance at Colorado Springs, (Sturgis); Boulder, (Bethel & Sturgis); Denver, (Bethel).

PERICHAENA CORTICALIS, *(Batsch) Rost.* Commonly found in the same situations as the preceding species, but distinguished from it by its somewhat more globose sporangia, smaller in size and less densely crowded, its scanty capillitium, and its usually larger spores.

Common at Palmer Lake and Denver, (Bethel); Colorado Springs, (Sturgis).

PROTOTRICHIA, *Rostafinski.*

PROTOTRICHIA FLAGELLIFERA, *(B. & Br.) Rost.* This remarkable species is reported from various parts of the State but the specimens are all scanty. The globose sporangia are either sessile or stalked, and vary in color from cinnamon-brown to a much darker shade with metallic iridescence. The spore-mass is olivaceous. The branching, tapering, spirally banded capillitium-threads are quite unique.

Specimens are present from Tolland, Yankee Doodle Lake and Arrowhead, all collected by Mr. Bethel.

LYCOGALA, *Micheli.*

LYCOGALA EPIDENDRUM, *(Buxb.) Fr.* The commonest of all *Myxomycetes* everywhere. Collected in Colorado at Colorado Springs and Glen Park, (Sturgis); Palmer Lake, Arrowhead, and on the South Platte, (Bethel).

LYCOGALA FLAVO-FUSCUM, *(Ehr.) Rost.* The large spherical æthalia of this species are commonly found growing singly or in clusters of three or four on fallen logs and stumps. It is a much larger form than the preceding, sometimes attaining a diameter of 5 cm. The cortex before maturity is horny and covered with minute translucent warts; at maturity the surface is minutely areolated and varies in color from tawny to brownish black. All of our specimens are from Boulder and were collected by Mr. Bethel.

In conclusion the writer desires to express his indebtedness to the many persons who have made his work possible by furnishing specimens and notes. Especially is such recognition due to the writer's collaborator, Mr. Bethel, whose indefatigable zeal and unusual powers of observation have enabled him to secure the greater number of specimens recorded in this paper.

Thanks are also due to Prof. H. L. Shantz, now of the University of Nebraska; Mr. M. C. Hall, formerly a student at Colorado College; Mr. L. C. Bragg, of Fort Collins; Messrs. H. F. Watts and D. M. Andrews, of Boulder; Mr. W. Heustis, of Denver; and Mr. Geo. Osterhout, of New Windsor, all of whom have contributed specimens.

It is almost unnecessary to state that the writer is under deep obligation to Mr. Arthur Lister, F. R. S. and to Miss G. Lister, of London, as well as to Professor T. H. Macbride, of the State University of Iowa, whose invaluable advice and opinion has at all times been as freely given as asked.

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COLORADO COLLEGE OBSERVATORY

F. H. LOUD, PH. D., Director.

No. 2. Stellar Variability and Its Causes. F. H. LOUD.

No. 3. On the Transformation of Algebraic Equations, by Erland Samuel Bring (1786). Translated and annotated by F. CAJORI.

No. 4. A Comparison of Temperatures (1906) Between Colorado Springs and Lake Moraine. F. H. LOUD.

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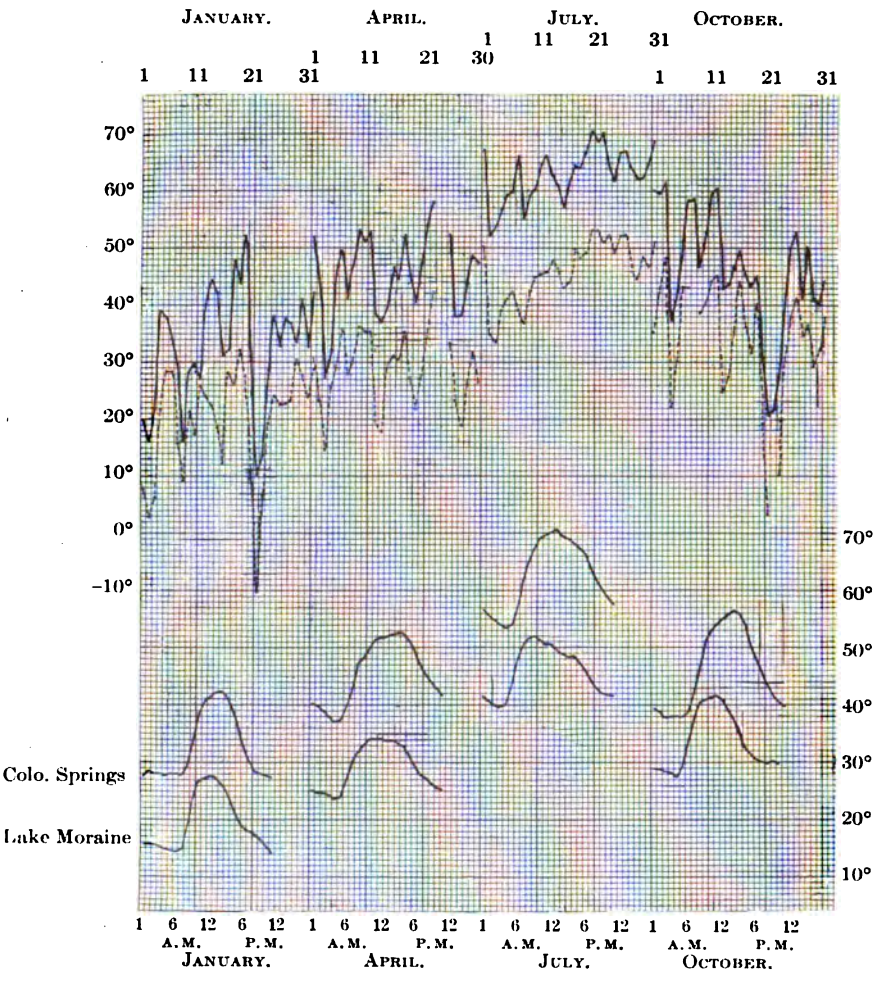
Comparative Temperatures, Colorado Springs and Lake Moraine, 1906.



In the upper diagram, the dotted line indicates the Lake Moraine temperatures; the full line, those at Colorado Springs.

confirmatory item that, in the legend, Medusa was indeed "winking," or rather napping, when Perseus obtained his fatal advantage.

Mira and Algol are now known to share their property of variability with a goodly number of companions. Miss Annie J. Cannon's "Second Catalogue of Variable Stars," recently issued from the Harvard College Observatory, includes 1265 entries. But this is not a complete census, for a cluster containing variables counts in this catalogue as a single object, while Professor Solon I. Bailey, of the same Observatory, has shown that the number of the separate variables to be found in a single cluster sometimes mounts into the hundreds. No wonder that under the title "Variable Stars" there is comprised a large chapter of the current study of astronomy.

Not only do the variables thus constitute a numerous class, but it is also a very heterogeneous one. It is far from showing the character of a natural group, whose members should possess a similarity of constitution, underlying their common phenomena. The question, "Why does the brightness vary?" raised by each single instance, is capable of a number of possible answers; and it would appear as if every cause which might conceivably produce such an effect exists somewhere in the universe of stars, and results in the production of a sub-class of variables.

The first natural partition of the class will be made when we separate those stars which actually emit more light at one time than at another from those which merely appear brighter or fainter at intervals, in consequence of some advantageous position as seen from the earth. Mira belongs to the first of these divisions, Algol to the second. The belief, that Mira's variability is due to changes taking place in the star itself, rests upon several lines of evidence. It will suffice to mention two, viz.: That the quality of the light varies with the quantity, and that the successive periods, from one light maximum to the next, exhibit marked individual differences, both in their

length, and in the intensity of brightness attained. The first of these facts is surely very significant. The spectroscope analyzes the light of the star, and proves that a dense enveloping atmosphere exerts at all times a notable amount of absorption, whose selective action on the different wave-lengths or colors of light produces a marked red hue and a highly characteristic type of spectrum. But when the star's maximum brightness is approaching, the character of the spectrum suffers change, and bright lines appear, indicative of unabsorbed radiation from incandescent hydrogen and other gases. This affords evidence that the increase of light is associated with physical changes, to which we must naturally look for its cause. Again the fact that the periods are of uncertain duration, longer and shorter following one another in an apparently capricious succession, shows that they are not caused by rotations or orbital revolutions, for these, by mechanical necessity, must either remain constant as regards the time required for their execution, or at most undergo a slow progressive change. Now, since rotations and revolutions, either of the body itself or of some other, furnish the only causes which can be imagined to produce periodic recurrences of advantageous position for visibility from the earth, it follows that a variability whose periods are irregular in length must be one of intrinsic brightness. In both these ways, then, Mira is proved to belong to the first of the two suggested classes.

Just what the physical changes may be which produce the star's alternations of brilliancy, is of course a large question. It has been customary to associate this problem with that of sun-spots. The Sun,—which is merely that star which, by reason of comparative nearness, is the most important to the human race and the most accessible to study,—exhibits at intervals of about eleven years a great increase in the number of spots spread over its surface. Were this periodic invasion of the spots to be augmented scores or hundreds of times, it

might make the Sun a noticeably variable star. The eleven-year period, however, though it presents the same inconstancy in duration which has been discussed, is always far longer than these stars are wont to show; moreover, the phenomena of sun-spots, examined spectroscopically, while agreeing in broad outline with the general character of the stellar variation, present discrepancies in details. On the whole,—as is perhaps to be expected,—the analogy sought between the Sun and Mira is so far incomplete as to raise questions quite as abundantly as it answers them.

The investigation of the physical conditions of Mira is practically that of a large proportion,—perhaps a majority,—of all the variables. For while in many cases the whole amount of the light received from the body is so small that spectroscopic examination cannot be made nearly so thorough, yet, in a host of them, whatever can be thus learned, or deduced from photometric study, presents a family resemblance to the traits of the type star. Indeed, a general agreement with Mira's spectrum,—resulting, as it naturally does, in a similar reddish tinge,—is so commonly associated with variability, as to have repeatedly led to the discovery of the latter in stars not previously known to exhibit it. The periods of these bodies are all to be reckoned in months;—in fact, that of Mira, which averages 331 days and a fraction, is very nearly of the length which stars of the same type most numerously affect. The irregularity of time, noted in Mira and in the Sun, exists in practically all these cases, and in some is carried to such an extent that the periodic character is entirely lost.

When, on the other hand, a star is found to undergo light-changes in a period of uniform length, such a period is apt to be much shorter. Some stars run through the entire course of variations in a few hours; more commonly three or four days or a week is required; rarely, if ever, more than a month. The characteristic regularity affords a strong presumption that,

with these bodies, a rotation or a revolution in an orbit is concerned; and in cases when the star is bright enough to allow of an accurate examination of the spectrum, it has been found possible to verify this presumption by actual measurement. For it lies within the power of that wonderful instrument, the spectroscope, not only to analyze the light of a star so as to detect the absorbent actions of specific metallic vapors existing in its atmosphere, and by their modifications to judge of the temperature and pressure existing there, but also to determine whether the body is approaching or receding from the Earth, and at what rate. This is accomplished by noting a minute shift of the spectral lines, in one direction or the opposite, when these are compared with the lines of spectra having a solar or terrestrial source. If it is thus found that a variable star has an alternating movement, the approach and recession together occupying just the time of a light-period, the indication is distinct that the explanation of the variation is to be sought in some effect of the revolution.

This, however, does not amount to asserting that the variability of light is in all these cases merely apparent; for there is still to be considered the possibility that revolution in an orbit may induce recurrent physical changes. Here arises the problem, how much may be attributed to the action of tides. The study of this subject has been brought into prominence by the investigations of George H. Darwin, the son of the great naturalist; and subsequently by those of See and others.

Whenever two bodies, as the Earth and Moon, or the Sun and Earth, are subjected to one another's attraction, the mechanical result will include not only a revolution about the common center of gravity, but also a tendency, depending upon the *difference* of attraction on the different parts of the same body, to deform the latter, elongating that one of its diameters which points toward the companion. The nearer the bodies are to one another, the more rapid will be

the revolution, and at the same time the stronger will be the tidal strain. The latter, acting upon a semi-fluid or yielding body, will in time modify both the revolution and rotation of the latter, and at last reduce these two movements to an equality of period, so that a permanently lengthened diameter will always point,—as in the case of the Moon,—within a moderate angle of the exact direction of the attracting mass.

Now, it is supposed that, in the case of two stars moving in elongated orbits, and at times very close together, the strains occurring in this process may be so violent as to bring about effects in temperature and perhaps in electrical state, which might manifest themselves in a variation of light, having the same period as the revolution.

It is clear that stars which should be induced in this way to manifest variability in the amount of light might be expected to show also, in the course of the period, some modification of its spectroscopic character, —changes in the relative intensity of different parts of the spectrum, or perhaps the occurrence of bright lines. Nor are such instances altogether wanting,—instances, I mean, in which a short and strictly regular period is marked by qualitative as well as quantitative light-change. But they are not so numerous as perhaps might be expected, and, so far as my acquaintance with their literature extends,— notably in Beta Lyrae,—the causes of variability thus accounted for appear to exist merely as accompaniments, relatively of minor importance, to others of a different nature. The existence of some tidal action in all cases of short-period revolution must be regarded as certain, but even in comparatively close pairs it seems to fall short of producing physical changes so great as to result in variation. In the *novæ* or temporary stars,—bodies whose rise to extraordinary brilliancy is a unique occurrence in their history,—there should, according to a theory but recently prevailing, be found the most favorable field for the study of tidal effects in an

extreme development. The extraordinary phenomena of these stars were thought to be caused by the falling together of two independently moving masses, which rush almost into collision, and then part from one another along hyperbolic curves. But the explanation has not proved satisfactory, and the problem of the *novæ* still awaits solution. Perhaps it may be found that each member of this class must assume an individual responsibility for its own outbreak, independently of any effect of companionship or environment.

Environment, on the other hand, is conspicuously a determining factor in variables of the "cluster-type," but the method according to which it operates remains unknown. These are stars which agree in remaining for the greater part of the time at the low-water mark of their luminosity, with a sudden leap into maximum brightness and a more gradual, but yet a rapid decline;—the whole series of changes being repeated with absolutely unvarying regularity in a period of the briefest extent, measured not in days but hours. With three or four exceptions, the stars which vary in this fashion are components of clusters. Other stars, their near neighbors, equally entangled as they are in the thicket of suns, retain a steady light. What difference in the stars themselves lies back of this diversity, who can say? The possibility may be admitted, that no such difference exists,—that the variation is due to some effect of surrounding matter on a radiation originally uniform. If so, the cluster variables would belong to the second rather than the first of our proposed pair of grand divisions. Let us then pass at this point to that second category.

Stars whose observed variation in light is to be regarded as due to no actual change in their own shining, but merely to our point of view,—the Earth being at one time more favorably situated to receive their radiation than at another,—must, according to what has already been noticed, bear at least two distinctive marks,—their light will show no important change

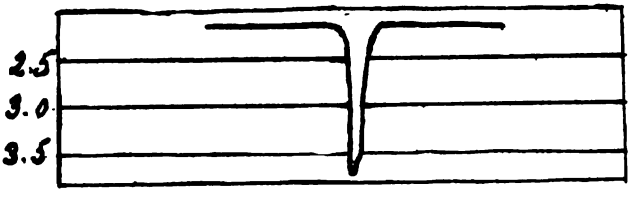
in quality coinciding with the variation in brightness, and the period of the latter will show a marked regularity in length. It is not necessary that the period should be absolutely unvarying, so that its duration now is the same to a second as a century ago; but if a change of length occurs this will proceed by a progressive modification, not by haphazard divergencies. The reason, as already stated, is that such regularity must characterize all movements of revolution, on which movements the recurrence of differing aspects must depend.

There are two classes of short-period variables, which exhibit the two marks just mentioned. The first consists of the eclipse-stars, of which Algol is the well-known type. In these cases, two bodies revolve in orbits about their common center of gravity, and the plane in which the motion takes place happens to pass nearly through the Earth. Twice in each revolution, therefore, the two are in line, as seen from our view-point; and, at one or both of the passages, one star is partly hidden by the other. Both bodies may be luminous, and then the minimum brilliancy can be no lower than that of the eclipsing star. Or one may be dark, as in the case of Algol, and then a total obscuration would be conceivable, though no such instance is on record.

The suggestion, that Algol's variation is thus brought about, is due, as already mentioned, to one of the discoverers of the variability. It had much to recommend it from the first. For Algol and similar stars are distinguished from all other variables by the fact that the brightness remains constant at maximum value during the greater part of the period, but drops suddenly to minimum, and after a brief interval is as suddenly restored. This interval, of course, is that of the passage of the dark satellite. This character of the variation is expressed in a diagram by the so-called light curve. This is merely the well-known device, so common in the presentation of statistics of every kind, in which, for instance, the varying price of some commodity is exhibited by the marking off on

a base line a number of points representing dates, at intervals proportional to the time elapsing from one to another, and then drawing a curve so that its height above each of the successive points of the base shall indicate the price of the article at the corresponding date.

In the light-curves, the brightness of the star, as observed from hour to hour of the period, takes the place of the price of the commodity, in this illustration. The light-curve of Algol will accordingly have the form shown in the figure below.*



Light-curve of Algol.

That such a light-curve is to be expected in eclipsing variables, is evident. But the eclipse theory was not regarded as proved, until the spectroscope had confirmed the existence of varying movement in the line of sight, thus enabling us to compare the light-curve with a velocity-curve. In the latter, the speed with which the body is receding from the Earth takes the place which in the light-curve is assumed by the brightness. There is a zero-line, representing the absence of movement, whether of approach or recession; and wherever the curve dips below this line, a proportionate speed of approach is indicated for the corresponding part of the period, or where the curve rises above the zero-level, a proportionate speed of departure. The average height may not be the same as the zero-line, because the revolving system may be continuously drifting toward us or away. Now the velocity-

*The two diagrams illustrating this article, are taken, with some change, the first from Prof. C. A. Young's "Manual of Astronomy," the second (originally due to Prof. Campbell) from Miss Clerke's "Problems in Astrophysics."

curve of an Algol variable shows the existence of a change in speed along the line of sight, recurring in the same period as that of the light-variation; and a comparison of the two curves shows furthermore that the light-minimum occurs at the same instant in the period with an average velocity in the line of sight,—that is, at the instant in which neither body of the revolving pair has any motion, toward or from us, except such as is due to the continuous drift already mentioned. The instant thus signalized is the one in which the orbital movements of the two bodies are directly *across* the line of sight, one being between us and the other. This coincidence is held to establish beyond reasonable doubt the truth of the explanation by eclipses.

The admission of this explanation at once affords the astronomer several interesting measures in relation to the variable, such as can be obtained for no other bodies in the universe outside the solar system. Still other figures are gotten by making some simple hypothesis, as, for instance, that of Vogel, that the two components are of equal density. That this should be exactly true in the case of Algol must be admitted to be in the highest degree improbable, since the bodies are under so different physical conditions that, while one is dark, the other is of greater intrinsic brightness than the Sun. The hypothesis, however, serves for the calculation of results of approximate validity. Without taking time here to separate the figures which depend on this hypothesis from those which do not, it will suffice to state the inferences drawn,—viz., that the luminous component is the larger body, having a diameter of about a million miles, while the dark one cannot be less than three-quarters of a million miles in diameter, and is more likely five-sixths of a million. The distance between their centers is about three and a quarter million. The space between the system of Algol and that of the Sun is believed to be something like six hundred millions of millions of miles. If so, its surface is fifty times as brilliant

as the Sun's, while the masses of the two bodies are respectively only four-ninths and two-ninths as great as his. A very slow change in the length of the period, alternately increasing and diminishing the latter within narrow limits, may be explained,—as by Chandler,—by assuming a third component, another dark body, at a distance from its companions of about a thousand million miles; or otherwise,—as by Tisserand,—as produced by the combined effect of an oblate form and elliptical orbit assumed to characterize the bright and dark members respectively of the binary system.

The number of known variables classed as similar in character to Algol appears from Miss Cannon's Second Catalogue to be thirty-seven. Twenty of them are bright enough to have been classified in respect to spectra, and of these all but two,—R Canis Majoris and Z Herculis,—are of the so-called Sirian type, which is believed to indicate an earlier stage of development than that of the Sun, and reveals an atmosphere in which hydrogen and helium predominate, while absorbing metallic vapors are nearly absent. They are thus in constitution almost as much as possible opposed to the long-period variables of the type of Mira.

There remains a second class of short-period variables, which has for its type-star Delta Cephei. These resemble the Algol family not only in the rapidity with which the variation is completed, but in the two suggestive characteristics on which emphasis has already been laid,—the virtual absence of qualitative light change, and the regularity of the successive periodic times. The orbital revolution which the second of these characters suggests is proved by the spectroscope to exist in all the cases,—now ten in number,—in which the brightness is great enough to have thus far invited the application of the requisite tests. From three to four times as many fainter stars may be presumed to resemble the specimens examined.

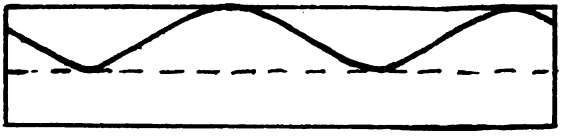
Thus far extend the resemblances to Algol; the remaining qualities present no less important contrasts. While the

Algol stars remain during most of their period at a uniform lustre, these continuously change in brilliancy. While the former usually lose and gain their brightness in approximately equal times, the latter with a very few exceptions require a much longer time to fade from maximum to minimum than to kindle from the latter to the former phase. The ratio of the times occupied by the two processes is, in the case of Delta Cephei, about as twelve to five, but larger discrepancies are not infrequently met. Very commonly the longer of these two segments is interrupted by a slackening or pause in the descent of the light;—sometimes, in fact, by an actual partial recovery of brightness. With pronounced unanimity, the stars of this class will have nothing to do with the Sirian type of spectrum affected by Algol and that clan; but exhibit, on the other hand, atmospheric conditions much more nearly resembling those of the Sun, and frequently belonging to a stage of evolution more advanced than his, though never attaining to the extreme so characteristic of the ruddy congeners of Mira. They are therefore probably more compact than stars of the Sirian type, and are to be regarded as exhibiting a fair degree of consolidation.

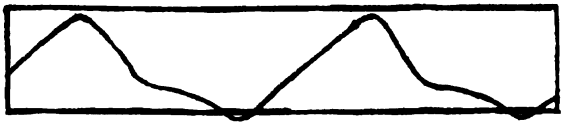
Finally, a most important contrast with the Algol variables is closely connected with the principal point of resemblance. The spectroscope shows in both cases that the variation is brought about by orbital revolution, but while in Algol and all its kin, the minimum brightness occurs always when the movement of the components is across the line of sight, thus proving the existence of eclipse, in the tribe of Delta Cephei it never occurs at this stage, and accordingly eclipses are wholly out of the question. In the attempt to find some other cause to take their place, it was early suggested that on the supposition of eccentric orbits, there might be some influence exerted at the periastron or point of closest approach,—some effect either in the way of extraordinary heating or, more likely, of intensified tidal action,—which should induce

greater intrinsic brightness. A more extensive acquaintance with the stars in question has developed a three-fold refutation of this hypothesis. First, there is no such pronounced change in the quality of light as should accompany a great physical modification; second, the orbits are often of but moderate eccentricity, thus presenting no occasion for such physical modifications of the bodies revolving in them; third, there is no constant relation between the positions of the periastron and the point of maximum brightness.

To Dr. Sebastian Albrecht is due the credit of pointing out the orbital position which *is* always coincident, in this class, with the rise to maximum brilliancy. This most significant coincidence becomes apparent as soon as the light-curve is brought into comparison with the curve of velocity in the line of sight. The summit of the one curve always approximately coincides with the lowest point of the other. Otherwise stated, the greatest brightness of every such star is attained when the latter is most directly approaching the Earth; or, in still other words, the star looks brightest to us *when we see that face which forms the advancing front of the body* in its onward motion along its orbit.



Zeta Geminorum: Light-curve.



Zeta Geminorum: Velocity curve.

The conclusion is hardly avoidable that the moving body is constantly brightest in front, and that the change in brilliancy as observed from the Earth, while possibly modified

a little by actual inequalities of luminosity, occurring from time to time, depends in the main upon the varying advantage of our position, as the bright side is turned more or less fully toward us. To account for the extra brightness of the front side, the easiest supposition is that the star is making its way through a cloud of particles, whose impact heats the face upon which they beat, raising it to incandescence.

So far, the explanation of the star's variation is not altogether new; it has been suggested by more than one speculator; but until Dr. Albrecht's discovery that the coincidence of greatest brightness with most rapid approach occurs not in one or two variables only, but in all of this class, the evidence previously existing for the hypothesis was not sufficient to secure it general favor. Even now it cannot be said to be accepted on all hands; it is a plausible conjecture, still on trial.

Our confidence in its validity will properly be enhanced if we see that it will reasonably account for some of the usual features of variation in this class, as they have been already recounted.

And first, we may note as not without significance to the hypothesis that this species of variables contains no stars of the Sirian type. Those tenuous bodies are quite possibly without any surface coherent enough to be heated in the way supposed. Particles colliding would penetrate deeply into the interior, and heat the whole mass rather than the exposed face. The greater solidity indicated by the solar spectrum is thus a requisite to this type of variability, just as statistics indicate. To picture the conditions required for the production of a variable like Delta Cephei, we may in the first place look for the simplest possible conception, upon which such modifications as may be necessary can afterward be imposed. Let us then imagine a collection of innumerable particles, devoid of any central mass. In the interior, the gravitative effects are balanced on all sides, and

there is little tendency to motion, but a firm pressure on each particle to maintain it in position. Into such a cloud, of an extent far surpassing the dimensions of the solar system, let us suppose that two large external bodies, one much greater than the other, drift in company. We will figure them as dark, solid spheres. Their advance into the interior is too slow to heat either to brightness; but the smaller is revolving about the larger, and this motion suffers resistance. The well-known effect will be that the revolution will be forced into narrower compass, and so will become more rapid. Gradually the orbit contracts, the speed increases, and the resulting heat augments. The tidal action has been such as to induce an equality between the times of rotation and revolution of the satellite, and this means that as one face is always turned toward the primary, so one face is always presented in the front of the orbital motion, where the impact of particles chiefly takes place. This face, constantly hotter than the rest of the surface, gradually becomes luminous. Meanwhile, the effect of the resistance, in diminishing the time of revolution, destroys the equality of this period with that of rotation. The tidal influence seeks to restore the agreement; and in the conflict of these two tendencies, it inevitably results that the revolution remains a very little more rapid than the rotation. In consequence of the lag of rotation, the bright spot already generated upon the revolving body is no longer stationary on its surface, and no longer round. It advances slowly along the equator, and takes on an unsymmetrical form, having one superlatively hot and bright end,—the part upon which the rain of meteoric particles is most rapid at the moment,—with a less vivid extension, in the direction of the part which was most exposed some hours ago.

As the body, thus unevenly heated, is viewed from a distant point, such as the Earth, the brightest end of the bright spot comes first into view,—causing a rapid increase in the apparent brilliancy,—followed by the trail of cooling

surface, which maintains the light at a slowly diminishing intensity, thus prolonging the visible decline. In this way the characteristic inequality of the rising and falling segments of the light-curve results as a necessary consequence from conditions which can hardly fail to exist.

For the sake of simplicity, the surface of the imagined body has been assumed to be rigid. It cannot, however, become luminous without becoming more or less volatilized; hence an absorbing atmosphere of metallic vapors will be created, producing the effect of the Frauenhofer lines in the spectrum. This atmosphere may vary in its constitution and density in different regions; thus a certain limited qualitative change of light from one part of the period to another is quite possible under the hypothesis. And indeed, a change of just the character to be expected,—marked especially by a varying proportionate intensity of light of high refrangibility,—does in fact exist. The general absorption, again, may slightly outstrip the increase of light, causing the brightest point, as seen from outside the atmosphere, to fall a little in advance of the heat center, instead of being drawn in the opposite direction toward the elongated trail of cooling matter. Thus the light-maximum would precede by a short interval the moment of most rapid approach to the Earth; and this seems to be often the fact, particularly in the case of Y Ophiuchi, whose period, being of the unusual length of seventeen and an eighth days, permits a closer examination of this point than is ordinarily practicable.

Thus the salient features common to variables of the type of Delta Cephei find their natural explanation in connection with the main hypothesis, except that interruption of the decline of brightness which has been picturesquely described by one writer as a "hump in the light-curve." Can this be similarly brought into relation to the rest? In an attempt to do so, one naturally turns to that feature of the orbit to which early theorists appealed,—though with no great success,—to account for the main variation. I mean, of course, the

ellipticity, in virtue of which the part of the orbit near or just succeeding the periastron may be expected to present some phenomena distinct from those of the rest of the curve.

From the point of view furnished by our hypothesis, these phenomena would be somewhat complex. First, the extra speed in the neighborhood of periastron would increase the frequency of collisions and so augment the total heating effect. But the point of greatest heating would move more rapidly along the surface,—the lag of rotation being now more pronounced,—and consequently the luminous area would be drawn out into a longer oval, and the extra heat distributed over a greater space. This longer oval would take more time in being carried by rotation across the face visible from the earth. To calculate the totality of the effect upon the variation of the star's apparent brightness would be a matter of much difficulty, more especially as some of the factors involved in the process of causation must be quite unknown. This much, however, in comparing one star with another, we might expect,—that the disturbance in the fall of brightness should be found to show some correspondence of magnitude to the ellipticity, and certainly in a precisely circular orbit should be altogether wanting. No accurately circular orbit is known, but some of quite moderate eccentricity have been measured, and it cannot be said that these present less well-marked "humps" in the light curve than others where the eccentricity is greater. At present, therefore, it is very doubtful whether the elliptical form of the orbit produces any effect at all upon the light-variation.

There is also to be considered the possible result of currents in the cloud of particles, and inequalities in its density. The condition supposed in a preceding paragraph, amounting to a practical uniformity and immobility of the resisting swarm, may be possible, but there is little reason to suppose that it would often be realized. Streaming motions are much more likely, and obviously are capable of producing any sort of

irregularity in the light-variation. In fact, it is a weakness of the fundamental hypothesis that it should so easily admit an element of capricious uncertainty into the explanation of a set of phenomena which on the whole,—comparing the stars with one another,—exhibit so good a degree of uniformity in their outcome.

There are some stars classed with this type, which, while going through their light-changes with all the punctuality as to time which characterizes other members of the well regulated family, are in no way to be depended upon as to the extent of variation. In some periods they will achieve a notable brightness, in others they will remain mediocre throughout, and this diversity is subject to no apparent law. In these cases, if the main hypothesis be sound, we may recognize the effects of inequalities and motions in the cloud of particles, while the ordinary example, in which each period substantially reproduces its predecessor, appears to require the simpler but theoretically less acceptable supposition, that the cloud is like a fog-bank, without motion and everywhere, in the vicinity of the variable, of about equal density.

It cannot have been unobserved that some parts of the explanation here given for short-period variability rest on much better evidence than others. To the writer it appears that the primary notion, of frontal heating,—wherein he has no claim to priority,—is almost certain to be included in the complete theory, when that shall be obtained. He knows, indeed, that it is accepted by at least one astronomer whose individual authority would be recognized by all as unsurpassed. Whether, on the admission of this part, any of the subordinate explanations, dealing with such matters as the unsymmetrical division of the light curve, etc., may be also regarded as plausible, is a question which he respectfully submits to the critical reader.

ON THE TRANSFORMATION

OF

ALGEBRAIC EQUATIONS

BY

ERLAND SAMUEL BRING

[In Lund, Sweden, 1786]

Translated from the Latin and Annotated by

FLORIAN CAJORI, Ph. D.

Professor of Mathematics in Colorado College

On the Importance of Bring's and Jerrard's Transformation of the Quintic Equation to the Trinomial Form.

Ce résultat remarquable . . . est le pas le plus important qui ait été fait dans la théorie algébrique des équations du cinquième degré, depuis qu' Abel a démontré qu'il était impossible de les résoudre par radicaux.

Hermite.

Un géomètre anglais, M. Jerrard, avait ramené toute équation du cinquième degré à une équation à trois termes dont un seul coefficient reste indéterminé. C'était un grand pas dans la théorie, puisque toute équation pouvait dès lors être résolue à l'aide d'une table à simple entrée. M. Hermite s'est appliqué à résoudre l'équation réduite de M. Jerrard, en introduisant comme auxiliaire la fonction qui exprime les relations entre le module d'une fonction elliptique et le rapport des deux périodes.

J. Bertrand.

B.* cum D.

Meletemata quaedam Mathematica

CIRCA

TRANSFORMATIONEM AEQUATIONUM ALGEBRAICARUM

QUAE

CONSENT. AMPLISS. FACULT. PHILOS.
IN REGIA ACADEMIA CAROLINA
PRAESIDE

D. ERLAND SAM. BRING,

HIST. PROFESS. REG. & ORD.
PUBLICO ERUDITORUM EXAMINI
MODESTE SUBJICIT

SVEN GUSTAF SOMMELIUS

STIPENDIARIUS REGIUS & PALMCREUTZIANUS

LUNDENSIS.

DIE XIV DECEMB. MDCCLXXXVI
L. H. Q. S.

LUNDAE
TYPIS BERLINGIANIS.

[*For obvious reasons, the title page, and the names and titles of the persons to whom the introduction is addressed, are reprinted here in the original.—F. C.]

S: AE R: AE M: TIS

MAGNAE FIDEI VIRO
NOBILISSIMO DOMINO

SVEN LAGERBRING
J. U. D.

REGIAE CANCELLARIAE CONSILIARIO DIGNISSIMO
HISTOR. AD REG. ACAD. CAROL. PROFESSORI CELEBERRIMO
ACAD. REG. E. E. L. L. MEMBRO MERITISSIMO
ACAD. CAROLINAE SENIORI MAXIME VENERABILI
CARISSIMAE MATRIS MEAE AVUNCULO OPTIMO ALTERIQUE
PARENTI INDULGENTISSIMO

S: AE R: AE M: TIS

MAGNAE FIDEI VIRO
NOBILISSIMO DOMINO

CAROLO A. HALLENBORG
IN REGIO DICASTERIO ABOËNSI
CONSILIARIO CONSULTISSIMO, GRAVISSIMO
VIRO NOBILISSIMO & AMPLISSIMO
DOMINO

MAGNO HALLENBORG
IN REGIO DICASTERIO JUNECOPENSI
ASSESSORI CELEBERRIMO, AEQUISSIMO
VIRO NOBILISSIMO AC STRENUISSIMO
DOMINO

ADOLPHO HALLENBORG
IN REG. LEGIONE SCANIAE AUSTRALI
CENTURIONI EQUESTRI MAXIME INCLYTO:

I have not thought it necessary to seek anxiously for Maecenases nor to have recourse to doubtful patrons under whose patronage this academic treatise may be published, while I am at liberty, along with many, to show my esteem and reverence for you, most noble gentlemen, as the surest patrons. And although it contributes most to your fame to show such a general kindness to men of learning as to be called and truly regarded as their chief favorites, yet *this* kindness which I have with others I shall honor [merely] in dutiful silence, since there are other things that touch me more closely. For such is the multitude of your kindnesses toward my father's household, and such the greatness of your unexampled goodwill, that, as a son whose parents make frequent mention of them, I could not be unmindful of those favors, and lest I should seem so to be, ought publicly to recall them. I therefore do recall them, and, in proof of the power of this grateful recollection, I have resolved to make this dissertation the public testimonial of my sincere devotion and allegiance to you, my great patrons. I earnestly pray and beseech you, therefore, to permit your most illustrious names to be inscribed upon this little work; and permit it the more, most urgently do I entreat you, because I owe to you the beginnings of my rising fortunes, and to you belongs, and rightly too, this account of my studies. And yet, do not merely tolerate my presentation of these first fruits to you, but graciously deign, with your customary kindness, to accept the *presenter*, your humble client, who yields to none in his loyal devotion. If, in accordance with your usual practice, you will kindly do this, you will not only put me under obligation by a new pledge of friendship, but also give me occasion for great self-congratulation. Henceforth I humbly pray the Supreme Deity, in his infinite goodness, to keep you long, O most greatly beloved patrons, in the uninterrupted course of happiness and in every form of prosperity. As long as I live I shall remain most devotedly attached to your most noble persons.

SVEN GUST. SOMMELIUS.

§ I.

There is nothing in algebra usually more desired, than the general resolution of equations into their roots. But, so far as the efforts of mathematicians have gone in the matter, this resolution is still so remote that, unless approximations are accepted as sufficient, the general method of resolving equations of the fifth degree is, as yet, enveloped in darkness. Of the artifices which have been employed to remove this difficulty, that must be least despised, in which the attempt is made to transform the proposed equation into another admitting of easier solution.

For example, let the quadratic equation $z^2+mz+n=0$, to be called A, be proposed for solution. Certainly nothing is easier than the formation of another equation B, in which a new quantity y is introduced by the relation $z=y-a$; for, upon substitution in equation A of the value $y-a$ for the unknown z, A is changed into an equation of this form:

$$\left.\begin{matrix} y^2-2a \\ +m \end{matrix}\right) y+a^2-ma+n=0=B.$$

This transformation being accomplished, I believe it to be clear to all that the solvable equation B can be disposed of without trouble. For, since I have assumed the equation $z=y-a$ and have left it within our power to fix the value of the letter a, it only remains for us to so determine this letter, that the second term vanishes in equation B, or that $-2a+m=0$, that is, that $a=\frac{m}{2}$. Accordingly, substitute for a its value $\frac{m}{2}$ in equation B. The result is:

$$y^2+\begin{matrix} \frac{m^2}{4}-\frac{m^2}{2} \\ +n \end{matrix}=0, \text{ or } y^2=\frac{m^2}{4}-n.$$

Since the second term in this equation has vanished, as desired, and is the only intermediate term in an equation of the second degree, the solution is obtained without much labor; for, necessarily

$$y=\pm\sqrt{\frac{m^2}{4}-n}=\pm\frac{1}{2}\sqrt{m^2-4n}.$$

From this follows easily the solution of equation A; for, as $z=y-a=y-\frac{m}{2}$, we have necessarily

$$z=-\frac{m}{2}\pm\frac{1}{2}\sqrt{m^2-4n}. \quad \text{Q. E. D.}$$

This solution of equation A is precisely the same as those taught in books on algebra, however different the mode of procedure. Moreover it is made plain from this example not merely what transformation of an equation means, but also how very fruitful [the process] may be in solving equations.

§ II.

It is certainly true that the above transformation will hold good in equations of any degree, but it is equally clear that, since only one letter is used, not more than one term can be eliminated in this manner. Let the proposed cubic equation $z^3+mz^2+nz+p=0=A$ be transformed, by the assumption $z=y-a$, into

$$\left.\begin{matrix} y^3-3a \\ +m \end{matrix}\right)\left\{\begin{matrix} y^2+3a^2 \\ -2ma \\ +n \end{matrix}\right\}\left.\begin{matrix} y \\ . \end{matrix}\right\}\begin{matrix} -a^3+ma^2 \\ -na+p \end{matrix}\Big)=0=B.$$

Now, in this new equation, the extermination of either the second or the third term, whichever one may wish, is easy; but, except in very rare instances, both terms can by no means vanish simultaneously. For, to effect the extermination of the second term, it is necessary that $-3a+m=0$, that is, that $a=\frac{m}{3}$. To remove the third term, it is necessary, however, that $3a^2-2ma+n=0$, or $a=\frac{m}{3}\pm\frac{1}{3}\sqrt{m^2-3n}$. But the evaluation of the letter a, according to which $a=\frac{m}{3}$, differs entirely from the evaluation of the very same a, by which $a=\frac{m}{3}\pm\frac{1}{3}\sqrt{m^2-3n}$. Nor can these evaluations agree with each other, except in the special case when $\frac{m}{3}=\frac{m}{3}\pm\frac{1}{3}\sqrt{m^2-3n}$,

that is, when $m^2-3n=0$, or $n=\frac{m^2}{3}$. If, therefore, the proposed equation should be $z^3+mz^2+\frac{m^2}{3}z+p=0$, then, without doubt, by putting $z=y-\frac{m}{3}$, it can be transformed into

$$\left.\begin{matrix} y^3 \\ -m \\ +m \end{matrix}\right) y^2 \left\{\begin{matrix} +\frac{m^2}{3} \\ -\frac{2m^2}{3} \\ +\frac{m^2}{3} \end{matrix}\right\} y \left\{\begin{matrix} -\frac{m^3}{27}+\frac{m^3}{9} \\ -\frac{m^3}{9}+p \end{matrix}\right\} =0, \text{ or}$$

$y^3-\frac{m^3}{27}+p=0$, in which equation not only the second term, but also the third has disappeared. But the case in which a possibility of this sort arises is indeed rare; so that, since the demand is, first of all, for a general method of removing the terms, the consideration on hand is altogether irrelevant.

Therefore, since of the aforementioned results, the one nearly always excludes the other, and there remains after the removal of either term nothing in the equation to be determined, by the evaluation of which still another term could be removed, it is very clear that generally but one term can be removed by the aid of this transformation. Since this is so, a cubic equation cannot as yet be resolved by the extermination of both of its intermediate terms. But it cannot be denied that the mere removal of the second term offers great facility in resolving equations of this degree, as is sufficiently evident from algebraic writings.

§ III.

Hardly any one doubts that this is true of the transformation of other equations, just as much as quadratic equations. Let, for example, this general equation be proposed:

$$z^a+mz^{a-1}+nz^{a-2}+pz^{a-3}+qz^{a-4}+\&c.=0=A.$$

Taking $z=y-\alpha$, there results, as all agree, even those who

have saluted the mathematical muses [only] from the threshhold.

$$\left.\begin{array}{l} y^a - \dfrac{aa}{1} \\ \qquad +m \end{array}\right\} y^{a-1} \left.\begin{array}{l} \dfrac{+a\,\overline{a-1}}{1\cdot 2}\,a^2 \\ \dfrac{-m\,\overline{a-1}}{1}\,a \\ \qquad +n \end{array}\right\} y^{a-2} \left.\begin{array}{l} \dfrac{-a\cdot\overline{a-1}\cdot\overline{a-2}}{1\cdot 2\cdot 3}\,a^3 \\ \dfrac{+m\,\overline{a-1}\cdot\overline{a-2}}{1\cdot 2}\,a^2 \\ \dfrac{-n\cdot\overline{a-2}}{1}\,a \\ \qquad +p \end{array}\right\} y^{a-3}$$

$$\left.\begin{array}{l} \dfrac{+a\cdot\overline{a-1}\cdot\overline{a-2}\cdot\overline{a-3}}{1\cdot 2\cdot 3\cdot 4}\,a^4 \\ \dfrac{-m\cdot\overline{a-1}\cdot\overline{a-2}\cdot\overline{a-3}}{1\cdot 2\cdot 3}\,a^3 \\ \dfrac{+n\cdot\overline{a-2}\cdot\overline{a-3}}{1\cdot 2}\,a^2 \\ \dfrac{-p\cdot\overline{a-3}}{1}\,a \\ \qquad +q \end{array}\right\} y^{a-4} + \&c. = 0 = B.$$

In this equation B, with the passing observation that the second term vanishes by placing $-aa+m=0$, and likewise that the third term disappears on taking

$$\frac{a\cdot\overline{a-1}}{1\cdot 2}\,a^2 - m\cdot\overline{a-1}\cdot a + n = 0,$$

thus requiring for the elimination of the fourth term that

$$\frac{-a\cdot\overline{a-1}\cdot\overline{a-2}}{1\cdot 2\cdot 3}\,a^3 + \frac{ma-1\cdot\overline{a-2}}{1\cdot 2}\,a^2 - n\cdot\overline{a-2}\cdot a + p = 0,$$

and that in general, to eliminate the Mth term, it is necessary to solve an equation of the Mth degree, I suppose that, for the rest, anyone easily sees that one term alone can be eliminated for the reason mentioned above; so that if it be true that algebraists once hoped to resolve any equation by means of a transformation which frees it from its intermediate terms, it must be confessed that the outcome up to this time has hardly met this expectation, and will never meet it, unless it happens that a different method of transformation is hit upon than the one used thus far.

§ IV.

What we have thus far presented with regard to the transformation of equations contains nothing new, almost nothing, in fact, which algebra could not teach while still squalling in its cradle. But although none of those things which pertain to mathematics have been left untouched and untried by the more than indefatigable lovers and devotees of this delightful science, yet that small portion of algebra which deals with the transformation of equations has been lying, as it were, in greatly undeserved oblivion, so that mathematicians have believed, and still do believe, that a transformation is clearly impossible, whereby, in an equation of the third and higher degree two or more terms would be made to disappear. Furthermore, just as if they wished to prevent all men in future from thinking about this, they have produced an argument which runs like this: *Let the opposite be assumed. Let it be assumed, for example, that this cubic equation* $z^3+mz^2+nz+p=0=A$ *can be transformed into another equation, cubic, to be sure, but pure* $y^3+a=0=B$, *in which both intermediate terms fail to appear. Then the value of* z *in equation* A *can be determined by the known value of* y *in equation* B. *But since only one of the roots of equation* B *is real, the other two are necessarily imaginary; but what concerns equation* A—*since it is a general one, so much so that it embraces within its own compass all cubic equations of any kind whatsoever, and without a shadow of a doubt may be made up of real roots—is that it clearly follows that a root of equation* A, *although real, can still be determined by a root of the equation* B, *although that is imaginary; that is, that what is real is determined by that which is imaginary and impossible. This is absurd. Ergo*[2].

We grant unreservedly that equation A, since it must be regarded as a general one, can have roots such that all may be real, and it is not to be denied that equation B must content itself with only one real root, since the other two are competing with a mathematical impossibility. No one can easily get around the possible reality of all three roots of equation A. Moreover, in the equation $y^3+a=0=B$, one root is

always $y+\sqrt[3]{a}=0$, which is real. But, in order that the other two roots may also be obtained, let the equation B be divided by the discovered root, the quotient will be $y^2-y\sqrt[3]{a}+\sqrt[3]{a^2}=0$. Hence, of the two remaining roots, one will be

$$y-\frac{1}{2}\sqrt[3]{a}+\frac{1}{2}\sqrt{-3\sqrt[3]{a^2}}=0 \text{ and the other}$$

$$y-\frac{1}{2}\sqrt[3]{a}-\frac{1}{2}\sqrt{-3\sqrt[3]{a^2}},$$

both of which are imaginary. So far, at least, no mathematical acumen is needed to follow the demonstration. But when it is contended further, that no real quantity can be determined by an imaginary quantity, then we certainly have something that is not far removed from a fallacy. This is the reasoning: *to be determined by something* is ambiguous, and certainly can be so used that it can be nothing but an absurdity to say that a real quantity can sometimes be determined by an imaginary quantity. But if such a usage of this expression should be admitted as this, viz., that a real quantity is made up of parts, one or another of which can sometimes be an imaginary quantity—(and that this is a legitimate usage must be readily granted) we adopt a method of reasoning intellectually difficult, to be sure, but one which can by no means be regarded as absurd. Whoever is even modestly acquainted with higher mathematics, or even with common algebra, must be familiar with this truth. It is evident e. g. that the cubic equation $z^3+nz+p=0$ can, by the rule of Cardan, be resolved into its roots, one of which is

$$z-\sqrt[3]{\frac{q}{2}+\sqrt{\frac{q^2}{4}+\frac{p^3}{27}}}-\sqrt[3]{\frac{q}{2}-\sqrt{\frac{q^2}{4}+\frac{p^3}{27}}}=0.$$

But if it should happen, as happen it sometimes must, that $\frac{q^2}{4}+\frac{p^3}{27}$ is a negative quantity, and therefore $\sqrt{\frac{q^2}{4}+\frac{p^3}{27}}$ an impossible quantity, then z, in that case, is the sum of two imaginary quantities, and yet it seems to be established beyond all dispute that in this particular case z is a real

quantity. This seeming contradiction can be obviated in no other way than by proving that that impossibility, which is involved in $\sqrt[3]{\frac{q}{2}+\sqrt{\frac{q^2}{4}+\frac{p^3}{27}}}$ is balanced by the impossibility involved in $\sqrt[3]{\frac{q}{2}-\sqrt{\frac{q^2}{4}+\frac{p^3}{27}}}$, so that the one neutralizes the other. Since this is the case, there is no reason why, by some similar compensation, the value of z in equation A, although it is real, may not be determined by the imaginary value of y in equation B. Thus the entire force of that demonstration with which we found fault is lost, so that now nothing is left except the authority of those eminent mathematicians by whose prestige, far more than by any sound reasoning on their part, this demonstration has been bolstered and puffed up, unless it be that such was the intentness of these famous star-gazers, and so great their flights to regions sublime, that they sometimes despised the common things of earth. However that may be, if any doubt still remains, we think that it will surely disappear as we now introduce some transformations which will quite conclusively secure the elimination of several terms in any equation whatever.

§ V.

It is certainly clear from what has been said above that for every transformation is required—

1. A given equation A to be resolved, and therefore awaiting transformation.

2. Some equation B to be found which will not only contain the unknown quantity of equation A, but also a new unknown quantity, so that the relation between these two unknown quantities may be determined by the help of equation B, which may be called the *subsidiary* or *mediatory* equation, since as a matter of fact there is no possible transformation of this kind, at least, without it.

3. An algebraic process, very often exceedingly difficult, to be sure, but always possible, by means of which that unknown quantity which is common to both A and B may be eliminated. When this elimination has been accomplished another equation C appears, which is usually called the *transformed* equation, and in which that unknown quantity which just previously had been introduced into equation B has that same very great importance which the other unknown quantity in equation A had. That the matter may be still clearer, let one of the above examples serve again as follows:

First, let this be the proposed equation which is to be transformed $z^3+mz^2+nz+p=0=A$.

Second, let this be the subsidiary equation $z+a-y=0=B$.

Third, let there be eliminated from these two equations A and B the letter z, and thus there will appear the transformed equation

$$\left.\begin{matrix} y^3 \\ -3a \\ +m \end{matrix}\right\} \left.\begin{matrix} +3a^2 \\ y^2 \ -2ma \\ +n \end{matrix}\right\} \left.\begin{matrix} y \ -a^3+na^2 \\ -na+p \end{matrix}\right\} =0=C.$$

When these have been carefully considered I believe that no one can doubt that this transformation is absolutely the same as the one which has been employed from the beginning of this dissertation. This one word ought to be added, that as yet it has not occurred to any of the mathematicians, so far as we have heard, to employ any other subsidiary equation except a simple equation of the first degree[3]. The result has been that we have had the use of only one undetermined letter, and that it has been possible to elide only one term from a given equation. But yet, to tell the truth, there is no reason whatever why there may not be a subsidiary equation of the second or even of a higher degree, and we shall thus see transformations by whose assistance two or more terms of any equation whatsoever can for the most part be eliminated.

§ VI.

First, let this be the equation to be transformed, $z^3+mz^2+nz+p=0=A$.

Second, let the subsidiary equation be $z^2+bz+a+y=0=B$.

Third, eliminating z from these two equations, this transformed equation results,

$$\left.\begin{matrix} y^3-mb \\ +m^2 \\ -2n+3a \end{matrix}\right\} y^2 \left.\begin{matrix} +nb^2 \\ \overline{-mn+3p}\cdot b \\ +n^2-2mp \\ -2mba \\ \overline{+2m^2-4n}\cdot a \\ +3a^2 \end{matrix}\right\} y \left.\begin{matrix} -pb^3+mpb^2 \\ -npb+p^2 \\ +nb^2a \\ \overline{-mn+3p}\cdot ba \\ \overline{+n^2-2mp}\cdot a \\ \overline{+m^2-2n}\cdot a^2 \\ -mba^2+a^3 \end{matrix}\right\} =0=C.$$

In this equation two letters, a and b, are brought to our notice, determinable at our pleasure, but they enter into the equation in such different ways that they have not at all the force of one letter. To eliminate either intermediate term we need no other device than this:

First, $\quad -mb+m^2-2n+3a=0=D$, and

Secondly, $nb^2-\overline{mn+3p}\cdot b+n^2-2mp-2mba$
$\qquad +\overline{2m^2-4n}\cdot a+3a^2=0=E.$

From equation D it is evident that $a=\dfrac{mb-m^2+2n.}{3}$ This value of a may be substituted in equation E in place of the same a and the result will be

$$b^2+\frac{-7mn+9p+2m^3}{3n-m^2}b+\frac{-n^2-6mp-m^4+4m^2n}{3n-m^2}=0.$$

The value of this letter b will easily be found, since it is only necessary to resolve the quadratic equation. When b is found, moreover, there can be no hesitation as to what a means. Hence it appears how the letters a and b ought to be determined so that the transformed equation C may drop both intermediate terms, $Q.\ E.\ F.$ So equation C is rendered pure and is easily resolved; but when the value of y is known, the value of z is easily found, after having resolved the quadratic equation B.

Furthermore, in this way it is easily perceived what that balancing of one impossibility by another, which appeared in

§ 4, really signifies. There are in equation C, after each intermediate term has disappeared, two imaginary roots upon which the two roots of equation A depend, although they can be real. But this dependence, whatever it may be, is meaningless except when there is some mediating equation B. And inasmuch as this equation was only simple, *i. e.* of one degree, there did not appear to be anything that could remove the impossibility of the roots of equation C. But if a quadratic equation were to appear as a mediating equation, both of whose roots can be imaginary, the whole problem would be flooded with light. For the impossibility which is involved in the roots of the pure cubic equation C, can be balanced by the impossibility which can be involved in the roots of equation B, so that when the impossibility of one is obviated by another, it cannot prevent all the roots of equation A from being real, and so on with the rest.

§ VII.

We may pass with unfaltering step from cubic equations of any kind, transformed in whatever way we wish, to biquadratic equations which are to be similarly transformed with the mediation of a quadratic equation. Thus, let this be the proposed equation, $z^4+nz^2+pz+q=0=A$, and let the second term be lacking, lest the problem be freighted with unnecessary difficulties. For if the second term were present we should certainly pay no moderate price in the effort to exclude it. Let the subsidiary equation be $z^2+bz+a+y=0=B$, and after eliminating the letter z it will be

$$\left.\begin{array}{l} y^4+4a \\ -2n \end{array}\right\} y^3 \left.\begin{array}{l} +6a^2-6na \\ +nb^2+3pb \\ +n^2+2q \end{array}\right\} y^2 \left.\begin{array}{l} +4a^3-6na^2 \\ \overline{+2n^2+4q}\cdot a \\ +6pab+2nb^2a \\ -npb+2nq+p^2 \\ -pb^3-4qb^2 \end{array}\right\} y$$

$$\left.\begin{array}{l} +a^4-2na^3+\overline{n^2+2q}\cdot a^2 \\ +3pba^2+nb^2a^2-\overline{2nq+p^2}\cdot a \\ -pnba-4qb^2a-pb^3a \\ +qb^4+nqb^2-qbp+q^2 \end{array}\right\} =0=C.$$

The second and third terms in this equation are very easily eliminated, if one sets down,

$$\text{First,} \quad 4a-2n=0 \text{ or } a=\frac{n}{2} \text{ and}$$

$$\text{Secondly, } nb^2+3pb+n^2+2q-\frac{3n^2}{2}=0$$

But the elimination of the 2nd and 4th terms seems far more profitable, since we thus reduce the biquadratic to a quadratic equation capable of very ready resolution. To make the matter still easier,—since it is evident from what has just preceded how the 2nd and 3rd terms can be eliminated,—let us assume that this has already been done. So when this is the proposed equation $z^4+pz+q=0=A$, let the subsidiary equation, $z^2+bz+a+y=0=B$, be assumed as before, and after the elimination of the letter z, it will be

$$\left.\begin{array}{r} y^4+4ay^3+6a^2+3pb \\ +2q \end{array}\right\} y^2 \left.\begin{array}{l} +4a^3+4qa \\ +6abp+p^2 \\ -pb^3-4qb^2 \end{array}\right\} y$$

$$\left.\begin{array}{r} +a^4+2qa^2+3pba^2 \\ +p^2a-4qb^2a-pba^3 \\ +qb^4-qpb+q^2 \end{array}\right\} =0=C.$$

If it be assumed in this equation that $a=0$ and also that $-pb^3-4qb^2+p^2=0=D$, then the second and fourth terms will drop out, whereby it is brought about that this equation, heretofore biquadratic in form, becomes for the time being quadratic. Therefore, since the value of b could easily be found by resolving the cubic equation D, and the value of y, also, would appear after completing the resolution of the quadratic equation C, the value of z cannot longer remain in doubt, as it emerges from its gloom when the quadratic equation B is resolved, *Q. E. F.*

§ VIII.

But if anyone wishes to have the 3rd and 4th terms eliminated, he comes at first glance upon a difficulty which is by no means so trifling and small as not to cause most anxious solicitude. Especially so since we have a right to fear that

difficulties of this nature, in transforming equations particularly of higher degree, will very often gain a foothold, and often be a great hindrance, in the matter of eliminating third, fourth and other terms. Of course for the simultaneous elimination of 3rd and 4th terms of a biquadratic equation it is required that

$$\text{First,} \quad 6a^2+3pb+2q=0 \text{ or } b=\frac{-6a^2-2q}{3},$$

$$\text{Secondly,} \quad 4a^3+4qa+6pba-pb^3-4qb^2+p^3=0.$$

When either the letter a or the letter b is eliminated from these, an equation results in which either the one or the other of these letters will be raised to a higher degree than z or the unknown quantity in the proposed equation, so that we are compelled to resolve an equation of less degree by resolving a more difficult one, and thus are driven from bad to worse. Yet whatever this difficulty may prove to be in other equations, it is certain that in the present case it can easily be removed. For if in the biquadratic equation first proposed the 2nd and 3rd terms are eliminated, (and we have seen that this elimination is possible), and if then a reciprocal transformation is begun, no mathematician will deny that by this operation a biquadratic equation is secured deprived both of its third and of its fourth term, *Q. E. F.*

As for the rest, as everyone clearly sees that any equation of whatsoever degree can, by means of a quadratic equation, be transformed into another equation in which, together with the 2nd term, may be made to disappear either the 3rd term, (the possibility of resolving a quadratic equation being assumed), or the 4th term, (the possibility of resolving a cubic equation being granted), and so on; so I suppose no one doubts but that in general by the help of this transformation more than two terms can never be made to disappear at the same time.

§ IX.

In order that three terms in a particular equation may be eliminated, one sees, then, that it is necessary to have a mediatory equation of at least the third degree.

So then let the proposed biquadratic be

$$z^4+pz+q=0=A$$

and let the subsidiary equation be

$$z^3+cz^2+bz+a+y=0=B,$$

which, after the letter z has been eliminated, will be

$$\left.\begin{matrix} y^4+4a \\ -3p \end{matrix}\right\} y^3 \quad \left.\begin{matrix} +6a^2-9pa \\ +3pbc+4qb \\ +2qc^2+3p^2 \end{matrix}\right\} y^2 \quad \left.\begin{matrix} +4a^3-9pa^2+6p^2a \\ +4qc^2a+6pbca \\ +8qba-pb^3 \\ -4qcb^2-3p^2cb \\ -5pqb+4q^2c \\ +p^2c^3+pqc^2-p^3 \end{matrix}\right\} y$$

$$\left.\begin{matrix} +a^4-3pa^3+3p^2a^2 \\ +2qc^2a^2+4qba^2+3pbca^2 \\ +pqc^2a-3p^2bca-p^3a \\ +p^2c^3a-4qb^2ca+4q^2ca \\ -5pqba-pb^3a \\ +qb^4+3pqcb^2+2q^2b^2 \\ -pqbc^3-4q^2c^2b+p^2qb \\ +q^2c^4-pq^2c+q^3 \end{matrix}\right\} =0=C.$$

To eliminate all three intermediate terms of this equation C, any one sees that, after due reduction, it is necessary that

First, $a=3\frac{p}{4}$,

Secondly, $24pbc+16qc^2+32qb-3p^2=0=E$,

Thirdly, $-2pb^3-8qb^2c+2p^2c^3-3p^2bc+4pqc^2$
$-6pqb+8q^2c+p^3=0=F.$

Then, if, from equations E and F, b is eliminated, the following equation appears:

$$\left.\begin{matrix} +\overline{24}^3p^5 \\ -5\cdot\overline{16}^2pq^3 \end{matrix}\right\} c^6 \quad \left.\begin{matrix} +7\cdot\overline{24}^3p^4q \\ -8\cdot\overline{16}^3q^4 \end{matrix}\right\} c^5 \quad \left.\begin{matrix} +540\cdot 24^2p^3q^2c^4 \\ +180\cdot 24\,p^6 \\ +500\cdot\overline{32}^2p^2q^3 \end{matrix}\right\} c^3$$

$$\left.\begin{matrix} +945\cdot 16\,p^5q \\ +400\cdot\overline{32}^2pq^4 \end{matrix}\right\} c^2 \quad \left.\begin{matrix} +15\cdot 32\cdot 36\,q^2p^4 \\ +4\cdot\overline{32}^3q^5 \end{matrix}\right\} c \quad \left.\begin{matrix} +7\cdot\overline{32}^2p^3q^3 \\ -27\,p^7 \end{matrix}\right\} =0=G.$$

This equation G is of the sixth degree. It is true, indeed, that the letter b might have been retained by eliminating the

letter c from equations E and F; but not even in that case does an equation of any lower degree appear. It may perhaps be supposed that there is nothing here but the appearance of a sixth degree, and that in reality, under this appearance, lies hidden an equation of lesser degree, especially since it can hardly be understood how the solution of a root of a biquadratic equation can bring about the solution of a root of an equation of the sixth degree. However that may be, in order to eliminate all the intermediate terms in a biquadratic equation, the resolution of an equation of the sixth degree seems to be a necessity. This is the same difficulty which was referred to in § 8, but to the cure of which the same medicine does not suffice, and which shall be touched upon again in due place. But that this difficulty in the elimination of three terms of any equation is not an insuperable one we shall see farther on.

§ X.

Let the proposed equation be

$$z^5+pz^2+qz+r=0=A,$$

in which the second and third terms are absent. Let the subsidiary equation be

$$z^4+dz^3+cz^2+bz+a+y=0=B.$$

Let the letter z be eliminated, with the following result,

$$\left.\begin{matrix} y^5-3pd \\ -4q+5a \end{matrix}\right\} y^4 \left.\begin{matrix} +3pbc+4qbd+5rb \\ +2qc^2+5rcd-3p^2c \\ +6q^2-4pr+5pqd+3p^2d^2 \\ -12pda-16qa+10a^2 \end{matrix}\right\} y^3$$

$$\left.\begin{matrix} -pb^3-4qb^2c-5rb^2d+3p^2b^2+9pbca+12qbda \\ -5rbc^2-3p^2bcd+2pqbc-5pqbd^2+15rba \\ +pr-8q^2 \cdot bd-11rq-3p^3 \cdot b+6qc^2a+15rda \\ +p^2c^2+pqc^2d+8rp-4q^2 \cdot c^2-9p^2ca+18q^2a \\ +4q^2-7pr \cdot cd^2-2pr+3p^3 \cdot cd-12pra+15pqda \\ +2p^2q+5r^2 \cdot c-p^3+3rq \cdot d^3+9p^2d^2a \\ -qp^2+5r^2 \cdot d^2-pq^2+rp^2 \cdot d-18pda^2 \\ +p^4-4q^3+8rpq+10a^3-24qa^2 \end{matrix}\right\} y^2$$

$$+\&c.=0=C.$$

In this equation C let the 5th and 6th terms be neglected, since we have nothing to do with them at present. But in eliminating the 2nd, 3rd, and 4th terms one sees that, of necessity,

$$\text{First,} \quad a - \frac{3pd+4q}{5} = 0 = D,$$

$$\text{Secondly,} \left.\begin{matrix} 15pbc+20qbd+25rb+10qc^2+25rcd \\ -15p^2c-3p^2d^2-23pqd-2q^2-20rp \end{matrix}\right\} = 0 = E,$$

and also, in the third place, the coefficient of the fourth term also is equal to zero, an equation which we will call F.

Now if in this equation F, in place of a we put its value $\frac{3pd+4q}{5}$ one cannot but see that letters b, c and d are not raised by this substitution to any higher degree than before. But when from equations E and F are eliminated either b or c or d, some equation of the 6th degree will inevitably appear which does not, probably, merely assume this form, and which cannot be forced down to a lower degree. And yet even this difficulty can, within a reasonable degree of certainty, be removed.

§ XI.

If in equation E, which is really nothing but the third term of equation C, in which, in place of a has been substituted its value $\frac{3pd+4q}{5}$, it is assumed that $b=\alpha d+\zeta$ and also that $c=d+\gamma$, the equation E will be changed into this equation,

$$\left.\begin{matrix} \overline{+15p+20q} \cdot \alpha \\ -3p^2+10q \\ +25r \end{matrix}\right\} d^2 \quad \left.\begin{matrix} \overline{+15p\alpha+20q+25r} \cdot \gamma \\ \overline{+15p+20q} \cdot \zeta \\ +25r\alpha-15p^2-23pq \end{matrix}\right\} d$$

$$\left.\begin{matrix} +10q\gamma^2 \\ \overline{+15p\zeta-15p^2} \cdot \gamma \\ +25r\zeta-2q^2-2rp \end{matrix}\right\} = 0 = G.$$

And if it is assumed that

$$\alpha = \frac{3p^2-10q-25r}{15p+20q} \text{ and}$$

$$\zeta = \frac{-15p\alpha\gamma - 25r\alpha - 20q\gamma - 25r\gamma + 15p^2 + 23pq}{15p+20q} \text{ and also}$$

$$\left.\begin{matrix} 10q\gamma^2 - 15p^2 \\ +15p\zeta \end{matrix}\right\}\gamma \quad \left.\begin{matrix} +25r\zeta \\ -2q^2 \\ -2rp \end{matrix}\right\} = 0,$$

any one can see that for the purpose of finding the value of ζ and γ the only resolution needed is that of a quadratic equation. When the values of α, ζ and γ, therefore, have been found and substituted in their places in equation G, the entire equation G must inevitably disappear by mutual cancellation of terms, with the result that in equation C the entire 3rd term also will disappear.

Having done this. let us substitute in the fourth term of the same equation C, in place of a its value $\frac{3pd+4q}{5}$ and likewise in place of b its value $\alpha d+\zeta$, and in place of c its value $d+\gamma$. Of course, since the letters α, ζ and γ are determined as we noticed a moment ago that they *must* be, the aforementioned fourth term is obliged to pass into an equation in which only one letter d appears as an unknown quantity. But since the degree of this letter d cannot exceed the third, it will be evident, by resolving the cubic equation, what value ought to attach to this letter so that the fourth term of equation C may disappear. So, then, when by the determination of a the 2nd term has disappeared, and by the determination of b, c, α, ζ and γ the third term has disappeared, and by the determination, finally, of d, the fourth term is made to disappear, it is evident that in any equation of the fifth degree the first three intermediate terms can be eliminated, *Q. E. F.*

But both the length of the subject and considerations of time forbid the proper discussion of these questions. Moreover I have not the leisure even to inquire into the nature of those resolutions of cubic and biquadratic equations which can be made, as we have seen, by means of a transformation, in order that, by comparing this method with the rule of

Cardan, a judgment may be rendered what especial difference there is between these methods.

Let this suffice for the present, and in withdrawing pen from paper let me bring this little work, whatever its merits or defects, to a respectful

End[6].

NOTES BY THE TRANSLATOR.

I.

BIOGRAPHY.

A biographical sketch of Bring, translated from the *Biographiskt Lexicon öfver Namnkundige Svenska män Tredje Bandet.* Upsala, Leffler och Schell, 1837:

"BRING, ERLAND SAMUEL. Born Aug. 19, 1736. (Parents: Jöns Bring, Rector of Ansås and Strösvelstrops churches, and Christ. Eliz. Lagerlöf). Student at Lund in 1750; 1757 he passed the law examination and was appointed assistant judge in the highest courts of appeal (Svea and Götha Hofrätt); returned to the university and was appointed 1762 Docent in the Faculty of Law; 1765 acad. notary; 1766 Ph. Mag.; 1770 he gave lectures in history, in place of his uncle, Chancery-Counsel Lagerbring; E. O. Adjunct in Philosophy the same year; Ord. Adjunct in History 1778, and Professor of History 1779. Promoter 1784; Rector of the university 1790. Died May 20, 1798. In 1791 he married Ingrid Cath. Ringberg, daughter of the Rector Nils Ringberg of Wäsby. No children."

"Mathematics was the favorite science of Professor Bring. Of his unremitting researches in this line only a very few have been publicly circulated in print; but in the academic library at Lund there are eight hand-written volumes containing treatises on different mathematical subjects, commentaries on Euler, Wolf, Palmquist, Hospital, and so forth, and also some works by himself on elementary mathematics, on geometry and algebra and also on differential and integral

calculus. He also made some calculations in chronology and astronomy. In the solution of higher equations Bring used Tschirnhausen's method in eliminating intermediate terms. Besides this he wrote on the theory of homogeneous functions and polynomials, etc. Concerning his scientific standing we refer to the statement of his nephew, Professor Ebbe S. Bring, on the occasion of the inauguration of Professor [Carl Johnson] Hill: 'But, if faith is to be placed in the most illustrious mathematicians of our time, it must be admitted that E. S. Bring, in the solution of equations of the fifth degree, has advanced to a point beyond which one cannot go. For, he shows that an equation of this degree can be reduced to three terms which, without doubt, is the limit, since it has been proved that the quintic cannot be reduced to two terms. Perhaps, indeed, certain of Bring's algebraical commentaries are such as not to displease the most renowned mathematicians of our age, although in most cases, the latter follow a shorter way. But this is a matter for mathematicians to pass judgment upon.'

"*Works:* 31 dissertations.- A memoir of Bishop Dr. Aud. Rydelius, for which he received, 1782, the prize of the Educational Association.

"(*Sources:* Sommelii Lex. Erud. Scan.—Parentation in Latin, held by Chancery-Counsel, Prof. Dr. M. Norberg. —Stâhls Biographic Notices of Professors at Lund.)"

II.

HISTORICAL NOTE.

Formerly the transformation of the general quintic equation to the trinomial form went by the name of "Jerrard's transformation." It was effected by G. B. Jerrard in his *Mathematical Researches* (Part II., Bristol and London, 1834), at a time when Bring's researches on this subject, made nearly half a century earlier, were not generally known. It was not until 1861 that the attention of mathematicians was called (by Mr. C. Hill) to the very remarkable dissertation of Bring, printed in 1786. Probably, the transformation of the quintic to the trinomial form will bear hereafter the

name of Bring, not only because Bring anticipated Jerrard, but also because the Swedish mathematician had a deeper insight into one important matter: He never claimed that the transformation led to the general algebraic solution of the quintic, while Jerrard persisted in making such a claim even after Abel and others had offered proofs establishing the impossibility of a general algebraic solution of the quintic.

III.

REMARKS ON THE TEXT.

(1). *To Preface.* This is dedicated by Respondent S. G. Sommelius to the Professor of History, Sven Lagerbring, a relative of his ("matris meae avunculo"), and to three other persons by the name of Hallenborg. Note that the author of the thesis is not Sommelius, but E. S. Bring, who presided at the examination.

(2). To § IV. This argument, which Bring refutes, is given (as C. Hill points out in his article on Bring in *Öfversigt af Kongl. Vetenskaps-Akademiens Förhandlingar, Årg.* 18, 1861, p. 317) in Abraham Gotthelf Kästner's *Anfangsgründe der Analysis endlicher Grössen*, Göttingen, 1760, § 290, which is as follows:

"290, Anm. So lässt sich, wenn 289 vorausgesetzt wird, jedes Glied der Gleichung wegschaffen, aber nur eins allein. Man kann auch leicht zeigen, dass keine Methode möglich ist, die allgemein aus jeder Gleichung alle Glieder bis auf das höchste und das letzte wegschaffte, wie der Herr von Tschirnhausen dergleichen erfunden zu haben glaubte. Gäbe es eine solche Methode, z. E. jede cubische Gleichung (283) in $y^3+t=0$ zu verwandeln, so dass x sich finden liesse, wenn man y hätte; so müsste das x der allgemeinen cubischen durch das y der reinen bestimmt werden. Aber das y der reinen hat allemahl zweene unmögliche Werthe (240) und das x der allgemeinen kann lauter mögliche haben, woraus schon zu übersehen ist, dass sich dergleichen Methode nicht erfinden lässt."

The advanced views expressed here by Bring on the subject of imaginary numbers are the more remarkable as practi-

cally all mathematicians of his time, excepting a few men of the first rank like Euler and Lagrange, looked upon imaginaries as unreal, mysterious, and to be avoided. Kästner, the very man whom Bring criticizes, held views on this subject that were in advance of those held by contemporary text-book writers. Moreover, Kästner was usually considered a rigorous writer, having in 1765 received from Pfeiffer the title of "Kästnerus rigoris mathematici studiosissimus." See C. H. Müller in *Abhandl. z. Geschichte der Math. Wiss.*, 18 Heft, Leipzig, 1904, p. 114. These facts show that, in the clearness of his argument on imaginary numbers, Bring was in advance of the rank and file of mathematicians of his age.

(3). To § V, VI. The method of transformation described here is no other than the so-called Tschirnhausen Transformation. Bring does not mention Tschirnhausen and he expresses himself in such a way as to lead to the belief that he re-discovered this method.

(4). To § VI, VII, VIII, IX. Bring's dissertation was followed in Sweden during the 18th century by only two papers, namely the two written by Pehr Tegman (1757–1810), professor of mathematics of the University of Lund. His papers of 1798 and 1799 are graduation-dissertations like that of Bring, written by the professor in charge, as was the custom at that time, and discussed and defended by the candidates for degrees. Tegman's articles are *Regula Cardani et methodus Bringiana radices inveniendi cubicas inter se collatae*, and *De aequatione biquadratica*, with Thunberg and Thelin as respondents, respectively. In these papers the cubic and quartic are discussed more fully than in Bring' thesis.

(5). To § IX, X, XI. An estimate of the importance of Bring's transformation is given by Felix Klein in his *Vorlesungen über das Ikosaeder*, Leipzig, 1884, pp. 143, 144, 207-209, 244. On page 244 Klein points out that Bring's process is encumbered by an unnecessary complication. Improvements were suggested also by S. Bills. See p. 90.

(6). The Translator has seen copies of Bring's original dissertation in the Library of Columbia University and also in the Public Library of New York City.

IV.

OTHER ARTICLES, AND BOOKS, TREATING OF THE TRANSFORMATION OF THE QUINTIC EQUATION TO THE TRINOMIAL FORM.

G. B. Jerrard, *Mathematical Researches*, Bristol and London, 1832–'35, Longman. Particularly Part II., 1834.

G. B. Jerrard, *An Essay on the Resolution of Equations*, London. Taylor and Francis, 1859.

G. B. Jerrard in the *Philosophical Magazine*, Vol. 7 (1835), Vol. 26 (1845), Vol. 28 (1846), Vol. 3, N. S. (1852), Vols. 23, 24, 26 (1862, 1863).

Sir W. R. Hamilton, "Inquiry into the validity of a method recently proposed by George B. Jerrard, Esq., for transforming and resolving equations of elevated degrees." *Report of the Sixth Meeting of the British Association*, Vol. V., 1837, pp. 295–348.

James Cockle, "On the Transformation of Algebraic Equations" *Mathematician* 1844, July. See also papers by him in *Philosophical Magazine* and *Cambridge and Dublin Mathematical Journal.*

C. Hill "Några ord om Erland Sam. Brings reduction af 5:te gradens equation" *Öfversigt af Kongl. Vetenskaps-Akademiens Förhandlingar.* Årg. 18, 1861, pp. 317–355.

Robert Harley, "A contribution to the history of the problem of the reduction of the general equation of the fifth degree to a trinomial form," *Quarterly Journal of... Mathematics.* Vol. VI., 1863, pp. 38–47.

Robert Harley "On Tschirnhausen's method of transformation of algebraic equations, and some of its modern extensions." *Report of the 39th meeting of the British Association*, 1866, London 1867, notices and abstracts, p. 2.

S. Bills in *Mathematical Questions with their Solutions. From the Educational Times*, London, 1864, p. 8, pp. 38–40, see also R. Harley, on pages 67, 68 of the same volume.

A. Cayley "On Tschirnhausen's Transformation," *Philosophical Transactions*, Vol. 152, 1862, pp. 561–578.

Serret *Cours d'Algèbre Supérieure* 1854, p. 462, note V. "Sur une application de la méthode de Tschirnaus." (First edition appeared 1849).

Hermite "Sur l'equation du cinquième degré." *Comptes Rendus*, Vol. 61, Paris, 1865, pp. 877, 965, 1073; Vol. 62, 1866, pp. 65, 157.

Gordan in *Mathematishe Annalen*, Vol. 13, p. 400.

J. Sierens "Entwickelung der Umformung der Gleichung $z^5-a_0z^4+b_0z^3-c_0z^2+d_0z+e_0=0$ in $y^5+y+\lambda=0$ mittelst der Tschirnhausenscher Substitutionen." *Astronomische Nachrichten*, Vol. 70, 1868, pp. 353–358.

W. E. Heal "On the removal of terms from the equation of the fifth degree." *Analyst*, Des Moines (Iowa), Vol. 5, 1878, pp. 78, 79.

Felix Klein *Vorlesungen über das Ikosaeder*, Leipzig, 1884, pp. 143, 207, 209, 244.

Johannes Rahts "Zur Reduction der allgemeinen Gleichung 5$^{\text{ten}}$ Grades auf die Jerrard'sche Form —— eine Weiterführung des von Hermite eingeschlagenen Weges," *Mathematische Annalen*, Vol. 28, Leipzig, 1887, pp. 34–60.

J. J. Sylvester "On the so-called Tschirnhausen Transformation." *Crelle's Journal*, Vol. 100, 1887, p. 465.

F. Cajori in Moritz Cantor's *Vorlesungen über Geschichte der Mathematik*, Vol. 4, Leipzig, (erste Lieferung) 1907, pp. 130–133.

A COMPARISON OF TEMPERATURES (1906) BETWEEN COLORADO SPRINGS AND LAKE MORAINE.

By F. H. Loud.

When the Observatory of Colorado College was fitted out with new meteorological instruments, some three years since, by General W. J. Palmer, it was planned to obtain comparative records of temperature, precipitation, etc., from a number of neighboring stations, particularly on the summit and slope of Pike's Peak, and sets of registering instruments adapted to this purpose formed part of his donation. Up to the present time, only one station, Lake Moraine, has successfully maintained observations of sufficient continuity to afford data for comparison throughout a whole year. The temperature record for Lake Moraine for 1906, while not absolutely continuous, is interrupted by no greater nor more frequent breaks than are to be expected in a station of this kind, and permits of satisfactory comparison with that of the Observatory. This record, the automatic tracing of a Richard thermograph, has been reduced to numerical statement in the same way as the similar records at the central station, as explained in several numbers of the Colorado College Publication, and the results contained in the two tables appended to this article may be compared with those for the same dates at Colorado Springs, as given in the Publication for July, 1907 (Science Series Vol. XI, No. 51). The figures for Colorado Springs are not repeated here, (except the monthly means at the foot of Table I) but the comparison is facilitated by the graphic representation of four months, January, April, July and October, forming the frontispiece of the present number.

Lake Moraine,—originally a natural lake, formed, as the name indicates, behind a dam resulting from glacial action in a past geologic period,—has in recent years been converted

into a reservoir forming part of the city water system of Colorado Springs, and the instruments whose record is here discussed have been under the charge of the city officer intrusted with the care of this reservoir, Mr. George DeLong. The actual work of observation has, I believe, devolved on Mrs. DeLong, whose attention to it has been very faithful and unremitting.

The lake is situated about 4,200 feet higher than the College instruments, or, more precisely, at an elevation of 10,246 feet, at the foot of the principal long rise leading to the summit of Pike's Peak, which is distant some three and a quarter miles to the N. W. in horizontal measurement, and rises about 3,900 feet higher. The difference of elevation has not been substantially modified by later measurements from the figures obtained by E. S. Nettleton, who surveyed the so-called "government trail" from Colorado Springs to the summit, by way of Lake Moraine, used by the U. S. Signal Service observers before the construction of the present carriage road and cog railroad, neither of which pass the Lake. It is interesting to note that Lake Moraine is associated with both Mr. Nettleton and Mr. Edward Copley, who together made the earliest meteorological record for Colorado Springs in the year 1871,—with the former in the way already indicated, and still more intimately with the latter, who for several years had his residence on its shore in the old Lake House, long since destroyed, but situated not far from the present city station.

The thermometer-shelter in which the Richard thermograph has been exposed is placed some 250 feet from the north shore of the Lake. It is not precisely of "standard" construction, but is well built and satisfactorily located, the exposure being as good as can reasonably be expected among the steep slopes of a mountain-side. The height of the instrument above the ground is about four feet.

The method of reducing the thermographic record is, in brief, to read off for each hour the highest and lowest indi-

cation of temperature, and to take the mean of these two as the mean temperature of the hour. The twenty-four means of each day are averaged to obtain the daily mean, and the 365 results so computed are given in Table I. Again, the mean temperature of a particular hour, (say 12 midnight to 1 A. M.), is averaged for the 31 days of the month of January, and the 24 results for the successive hours of the day are shown as the "Mean Daily March of Temperature" for that month, forming, with the corresponding figures for April, July, and October, the contents of Table II.

For these four months, the statistics embodied in the two tables are brought into comparison with the corresponding figures for the same dates at Colorado Springs (College station) by the graphic representation presented in the frontispiece, the upper portion of which corresponds to Table I and the lower to Table II. For convenience, the 31st day of January and July, in the upper part of the figure, is plotted on the same vertical line with the first day of the succeeding month of the diagram (April or October) so that the diagrams overlap to that extent. In the lower part of the figure, as only twenty-four vertical lines are needed to each monthly diagram, the curves are separated by gaps of six spaces.

As already mentioned, there are a few instances in which the Lake Moraine record was interrupted for some hours at a time. When such breaks are as much as twelve hours long, the record of the day has been omitted from the diagram, thus making a gap in the line. (That appearing in the April diagram is due to a similar failure of record at Colorado Springs.) In the numerical data of tables I and II, however, these gaps have all been supplied by interpolations, made in the following manner: Suppose, for instance, that the gap occurs in a day of August, and is six hours long, extending from 2 P. M. to 7 P. M. inclusive. The mean hourly change from 1 P. M. to 8 P. M. is given by the data of Table II for the month of July, (and evidently, in every case, for a month no

further away than that preceding or that following the one in which the gap occurs). It may appear that the recorded figure for the August day in question was 2 degrees higher than the July mean at 1 P. M. and 1 degree lower at 8 P. M. This fall of 3 degrees is then apportioned equally through the six missing hours, and the interpolated figures are those of the July mean, algebraically increased by a correction diminishing uniformly from +2 to −1. (The correction is made to tenths of a degree, and the nearest whole number to the result is used in each case as the reading for a particular hour.) In this way, the mean values for the day and months are not seriously affected by the breaks, even though the hours for which the record is wanting should happen to differ considerably from normal values of temperature.

The foregoing explanations have taken so much of the space intended to be given to this article, that remarks upon the meteorological significance of the two records must be left in large part to the reader. In the curves indicating the daily march of temperature, it is of course apparent at a glance that the rise in the morning hours is more rapid at the mountain station, leading to an earlier maximum. In July, the effect of the shade of thunder clouds, so abundant in the middle of the day and particularly after noon, is especially observable at Lake Moraine. In consequence of their prevalence, the maximum insolation is no doubt reached, even at Colorado Springs, before twelve o'clock of the average day; but at Lake Moraine, where the heat thus received is not retained by so heavy an atmospheric screen, it appears that the mean temperature, as well, reaches its maximum in the forenoon.

The upper diagrams of the page afford an opportunity to compare the time of onset of the cold waves and of the rises in temperature, when these are sufficiently far apart in their occurrence at the two stations to be distinguished in the means for whole days. Professor J. E. Church, in a paper pub-

lished in the Monthly Weather Review, June, 1906, shows that his mountain station in Western Nevada ordinarily feels the effect of a cold wave in advance of the neighboring valley station. The occurrence of the contrary relation on the eastern slope of the Rocky Mountains in Colorado has often been noticed, an elevated station being observed to retain a mild temperature for a considerable time after a cold wave has set in at a lower level. If I am not mistaken, this fact has been pointed out in a published comparison of Denver observations with those of Dr. W. A. Jayne, made at Georgetown, Colorado, in Clear Creek Canon, but I have not now at hand the material for verifying this reference. In the January diagrams of the present publication, it will be observed that the beginning of the fall in temperature, January 4th, was manifested in the daily means a day earlier at Colorado Springs than at Lake Moraine, although the *coldest day*, in each cold wave of January, 1906, appears to have been the same at both stations, and the most remarkable fall of temperature during the month began (January 17) earlier at the higher station, as in Nevada.

TABLE I.

DAILY TEMPERATURES, 1906, AT LAKE MORAINE.

Means from 24 hourly thermograph records.

Day.	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	7.8	23.8	10.8	30.6	33.4	37.0	50.0	51.4	45.7	35.2	36.0	31.3
2	2.9	25.0	5.3	23.3	29.2	39.7	34.9	50.3	35.5	42.0	21.6	37.6
3	6.3	29.0	18.3	14.6	37.5	38.0	33.5	48.8	37.5	48.3	30.7	38.0
4	21.7	12.4	23.0	25.5	41.3	45.6	39.0	48.1	44.5	22.1	34.6	28.0
5	28.3	16.6	14.6	29.3	26.0	50.7	41.0	47.8	46.3	30.3	38.2	23.0
6	28.2	13.5	14.4	35.8	30.1	44.1	42.2	49.2	48.7	43.3	31.7	32.2
7	15.9	15.5	27.3	27.9	35.2	40.2	39.1	47.1	49.3	43.1	34.3	36.5
8	9.1	18.3	29.9	30.0	33.5	46.3	36.8	47.8	48.4	47.6	37.3	30.6
9	21.3	17.0	20.9	36.3	40.5	50.8	42.6	50.9	47.0	38.6	39.0	27.8
10	17.5	17.5	24.4	35.4	38.4	54.0	44.9	47.2	42.7	40.5	39.6	29.0
11	25.7	19.0	24.8	35.3	43.4	49.8	45.4	48.1	46.6	44.2	34.5	38.4
12	24.0	18.8	27.5	19.6	39.0	48.5	45.8	52.1	44.5	45.0	38.2	31.7
13	22.5	16.5	27.2	17.8	34.4	54.4	47.7	54.0	46.7	24.8	37.3	19.7
14	19.0	20.3	21.3	29.4	38.5	53.2	46.5	50.0	38.0	27.4	39.2	7.0
15	12.2	25.0	13.1	31.0	45.6	52.4	43.0	49.6	41.6	35.4	40.0	6.4
16	28.1	21.7	12.3	30.5	48.5	58.7	44.0	53.2	32.7	44.0	20.2	7.4
17	26.0	25.1	18.4	35.2	45.7	42.8	49.9	52.4	31.6	36.2	8.8	12.3
18	32.1	22.7	10.0	27.2	44.9	40.9	48.3	51.8	32.7	31.6	-1.2	21.5
19	27.5	28.1	6.6	21.7	43.5	45.9	49.3	52.4	37.9	40.1	-3.1	19.5
20	10.8	24.7	21.0	27.7	43.2	36.8	53.0	53.0	42.8	19.2	5.7	22.5
21	-10.2	33.2	28.2	34.4	44.3	51.9	53.0	55.8	41.9	3.3	17.3	30.0
22	6.7	21.3	30.7	42.3	41.4	50.9	51.1	49.7	41.3	3.1	9.0	29.6
23	19.3	13.5	30.0	42.3	34.7	35.2	52.2	42.5	43.2	10.2	16.7	33.5
24	24.0	15.7	32.0	32.2	29.6	36.8	49.3	47.3	46.6	30.1	23.4	29.4
25	22.6	21.6	31.7	33.2	36.4	44.4	52.1	42.5	47.4	38.0	12.3	33.2
26	22.7	19.7	25.8	23.3	39.2	51.7	52.3	39.8	33.4	41.2	12.8	31.5
27	23.4	34.1	23.1	18.9	45.7	53.7	45.9	44.9	40.8	34.6	26.8	26.8
28	30.3	29.7	19.0	26.2	45.8	50.5	44.6	46.5	40.6	36.5	27.9	20.1
29	27.8	.....	19.7	31.6	35.2	50.4	48.4	45.9	41.0	29.3	24.0	15.9
30	23.9	.....	24.2	26.3	36.8	52.0	46.6	40.6	43.6	32.2	19.2	16.5
31	28.8	.....	35.2	.....	36.0	.....	51.0	45.2	.....	37.9	.....	15.9
Sums	606.2	599.3	670.7	874.8	1196.9	1407.3	1423.4	1505.9	1260.5	1035.3	752.0	782.8
Monthly Means	19.6	21.4	21.6	29.2	38.6	46.9	45.9	48.6	42.0	33.4	25.2	25.3
Means at Colorado Springs	32.6	31.3	27.8	45.2	53.9	61.4	62.9	65.5	57.7	46.0	35.3	37.6

TABLE II.

DAILY MARCH OF TEMPERATURE,

LAKE MORAINE, 1906.

Hour Ending	Jan.	April	July	Oct.	Hour Ending	Jan.	April	July	Oct.
1 A. M.	15.7	25.2	41.6	28.9	1 P. M.	27.5	34.2	50.8	41.7
2 "	15.7	24.8	40.7	28.7	2 "	27.3	33.9	49.7	41.0
3 "	15.6	24.7	40.1	28.5	3 "	26.5	33.8	48.9	39.4
4 "	15.5	24.4	39.7	28.3	4 "	25.0	33.5	48.4	37.8
5 "	14.9	23.8	40.0	27.4	5 "	22.6	33.0	48.5	35.4
6 "	14.6	24.1	43.2	26.9	6 "	20.3	31.6	47.5	32.6
7 "	14.5	26.9	47.9	29.3	7 "	18.6	29.7	46.1	31.6
8 "	14.9	30.1	50.3	33.6	8 "	17.9	28.1	44.2	30.5
9 "	18.2	31.9	51.4	37.7	9 "	17.5	27.4	42.9	30.1
10 "	23.7	33.1	52.0	40.4	10 "	16.6	26.4	42.0	29.8
11 "	26.7	34.1	51.5	40.9	11 "	16.3	25.7	41.8	30.0
12 M.	27.3	34.1	50.8	41.4	12 n't	16.1	25.5	41.7	29.7

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METEOROLOGICAL STATISTICS FOR 1907.*

By F. H. Loud.

Building, Equipment, and Exposure of Instruments.

The observatory building of Colorado College, erected in 1894, was the gift of Henry R. Wolcott, Esq., of Denver. Its geographical position, as determined by reference to neighboring stations of United States surveys, is, in latitude, 38 deg., 50 min., 44 sec.; longitude, 6 hours, 59 min., 16.5 sec.; elevation, about 6,040 feet.

The astronomical equipment consists of a four-inch equatorial telescope, given to the College by the donor of the building, and a transit instrument and clock, given in 1900 by the late Charles S. Blackman, of Montreal, Canada.

The meteorological equipment in part antedates the building, the nucleus having been obtained from the U. S. Signal Service, when the college first became a voluntary weather station in 1878. Several additions of apparatus were subsequently made. Much the most noteworthy, during the earlier years, was that of a set of Draper self-recording instruments, due to the generous interest of the late Dr. S. E. Solly, of Colorado Springs, who was seconded by Mr. B. W. Steele, editor of the "*Gazette*," in his lifetime one of the staunchest advocates of local enterprises in science, and by other friends. Of these Draper instruments, the barograph alone remains in use. In November, 1903, the quadruple register with all the apparatus connected with it, together with a number of other instruments, especially hygrometers of different kinds, were

*The matter introductory to the tabulated statistics, presented under this head, is in the main reprinted from the Colorado College Publication (General Series No. 16) which appeared in April, 1905. A somewhat more detailed account than is here given of the process used in preparing the Daily Record sheets from the instrumental data may be found in that issue. In the number for October, 1904, is contained a more extended description of the meteorological instruments, including an untechnical account of the principles of their construction.

given by General William J. Palmer, who has since provided for the expense of reducing and publishing the observations and records.

The exposure of instruments pertaining to wind, sunshine and temperature is on the roof of Hagerman Hall, a building standing east of the Observatory and on higher ground. Here is the standard thermometer shelter, 10 feet above the roof, 54 feet above the ground and 69.5 feet above the level of the Observatory floor. It contains maximum and minimum thermometers, a whirling psychrometer, and a Richard thermograph. Higher by 7 feet, and at horizontal distances of 11 feet from the shelter and 341 feet from the Observatory door, is the wind vane, on the iron support of which are attached the Robinson anemometer and the electric sunshine recorder. The cable connecting these three instruments with the quadruple register in the Observatory is laid underground.

Near the middle of the flat roof of the Observatory, which affords, on the east side of the dome, a clear space 37 feet long (east and west) and 27½ feet broad, and is 16 feet above the ground, is the rain gauge, provided with a tipping-bucket attachment for registration. It is electrically connected with the quadruple register, which is in the same building, on the first floor. Here, also, on the north side, is a window shelter for the exposure of the hygrometric apparatus, exclusive of the whirled psychrometer. This consists of a Richard registering psychrometer, a dew point apparatus, and a hair hygrometer. The Draper barograph is on the south wall of the same room, but the barometer read at the tri-daily observations, as well as the Richard barograph, is in the upper story of Hagerman Hall, at an elevation exceeding that of the Draper instrument by 43.2 feet.

THE "DAILY RECORD."

The summaries for the months, which are presented in tabular form in the pages following, are derived in the main

from a prior set of tables, one for each day, called the Daily Record, which is preserved in MS. form, along with the original sources, at the Observatory. In the Daily Record is tabulated first, the wind-direction, the register of which, as automatically made upon the instrument, consists of four rows of dots, for N., E., S., and W., made at intervals of one minute. The count of dots in the four rows, for each hour of the day, occupies the beginning of the record, followed by the *mean bearing* for that hour, deduced from the preceding by a specially adapted traverse table. Next is the hourly wind-velocity, obtained by counting the anemometer record. Succeeding columns exhibit the resolution of this velocity into two components determined by the bearing, one directed along the meridian and the other at right angles thereto.

After the wind-record come the two other data derived from the Quadruple Register, viz.: the rainfall and sunshine, for hourly periods, and after these the pressure as shown by the trace of the Draper barograph at the end of the hour. The temperature, which is next on the record, is obtained from the Richard thermograph, by noting the highest and lowest indications in the course of each hour, and taking the half sum of these as the mean hourly temperature. The humidity records and those on the state of the sky, whether "clear." "partly cloudy," or "cloudy," are taken from the tri-daily observations.

The foregoing data can in large part be obtained from supplementary sources in case the record of the instrument ordinarily used should for any reason be temporarily unavailable. Thus, if a gap occurs in the Draper register of pressure, it can be filled from the Richard barograph with a suitable correction for difference of elevation. The sunshine record is similarly supplemented by the indication of a photographic instrument, of a design originating at the Harvard College Observatory, and belonging to the station of the Western Association for Stellar Photography, at Knob Hill,

about two miles east of the College grounds. A small anemometer register at Hagerman Hall is actuated by the same electric current which goes to the corresponding pen in the larger instrument at the Observatory. An interesting term of comparison with the College observations is afforded by those of Mr. Emery P. Moon, who kindly furnishes daily readings of maximum and minimum thermometer and rainguage, made about a mile east of the College at 222 Cedar Street.

Except in the case of the Hagerman Hall anemometer, the sources of supplementary data above named are quite different from the primary ones, either as respect construction or exposure of instruments, and hence discrepancies between the parallel records are continually presented. This in some cases is hardly to be regretted, since a comparison may elicit additional information upon the actual physical conditions. In other cases, and particularly in that of the two sunshine recorders, the divergencies are much greater than could be desired, and occasionally, in fact, their simultaneous records would hardly be believed to belong to the same day. Each instrument gives a more or less defective account of the sunshine in the early morning hours. In the statistical tables of this Publication, in this, as in former years, no attempt is made to supply this omission, but the data are given as derived from the instrument. This fact accounts for an apparent disagreement with certain other compilations, drawn from the same original source, in which it is the customary practice to add to the instrumental record a correction determined empirically from month to month, by observing how much the record falls short of 100 per cent. on one or more selected days observed to be cloudless.

THE "MONTHLY SUMMARY" AND OTHER TABLES.

The manner of deriving the tables annually printed from the MS. "Daily Record," requires little explanation. The

first column, "Mean Temperature for Twenty-four Hours," is the mean of the results for the separate hours, obtained as above described from the Richard thermograph. The "Extremes," in the next two columns, are the highest and lowest points reached by the temperature between the beginning of the calendar day, (at 12 o'clock midnight) and its close, twenty-four hours later. They are taken from the readings of the maximum and minimum thermometer, when these are applicable; yet in numerous cases, these readings are discarded for those of the Richard instrument. For instance, it occurs not seldom in this climate that at the time of setting the maximum thermometer (6 P. M.), the temperature is higher than is reached at any hour of the following day. Reports based upon the record of the latter thermometer will hence show for the second day a maximum temperature which does not belong to that day at all. Again, the minimum thermometer is sometimes read lower at noon than in the morning, and lower still at 6 P. M., when its daily indication is recorded; while the tracing of the Richard instrument may show that the first reading is nearest the truth, the subsequent fall of the index being presumably due to vibration of the instrument caused by wind. The avoidance of misleading records of these and similar kinds produces an appreciable difference between the contents of these two columns and those presented in such reports as are drawn from the records of the maximum and minimum thermometers alone. The "Hours of Extremes" are taken from the indications of the Richard thermograph. When several hours have equal readings, the hour named is that nearest the middle of the period of maximum temperature, or having the highest temperature in adjacent hours. Inspection of these columns enables the reader to distinguish the days in which the normal progress of temperature was disturbed by irregular movements.

In the six columns under "Psychrometer" are given the results of all the tri-daily observations, individually, while in that of "Clouds at Observations," the three estimates of cloudiness, made at the same hours, and each expressed in tenths of sky covered, are combined into one sum, thus indicating the cloudiness of the day on a scale of 30. At the foot of the column, the mean of the daily estimates is reduced to the more convenient form of a percentage; the number denoting entire obscuration being advanced from 30 to 100, and others in proportion.

The three columns following contain the record of sunshine. In the first six months of the year, this is taken from the Quadruple Register, giving the indications of an air-thermometer. At the beginning of the year, these were fairly satisfactory, becoming less so as the year advanced, until in June, although some of the days should unquestionably have had a record of unbroken sunshine, the indication for none of these exceeded 71 per cent. of the possible duration. In July the column is filled from the Knob Hill photographic record, the other being now so much impaired as to register only about half the true amount; and this use of the substitute record continues till October 6th, with the exception of the last week in August, for which the report furnished by the College to the City Department of Public Health (and subjected to the rather arbitrary augmentation for unrecorded morning hours already mentioned), proved afterward to be the only available source.

In October, a better adjustment of the instrument connected with the Quadruple Register was secured, and this instrument furnished the remaining records employed as far as the 27th of December, when it was again necessary for temporary causes to fall back upon the photographic tracings for the last five days of the year.

The "barometer" column, like those relating to the psychrometer, gives the result of individual eye-observations, but in

this case is restricted to the reading taken at noon. Were this observation taken about fifteen or twenty minutes earlier, the indications are that it would, in the long run, afford a good average value for the daily mean.

The seven columns next in order relate to the wind. The first gives the total run of miles for the day, as counted from the Quadruple Register. When the indication of this instrument is lacking for a number of hours, the deficiency is supplied for the interval as a whole by recourse to the dial attached to the anemometer. Thus there is no unfilled gap in this record, though in several instances the total sum for two or more consecutive days cannot be distributed to the separate days, but is presented only as a gross amount. The four columns showing the sums of the N., S., W., and E., components from the Daily Record might, of course, have been reduced to two without effect on the computation of the resultant, but there would so be lost an interesting index of the variability of the wind, showing in what days the air-movement was substantially all in one direction, and in what others the flow from one quarter was nearly neutralized in the course of the same day by counter-currents. The direction and magnitude of the resultant are given in the last two of the wind columns.

Owing to gaps in the record of either the anemometer or anemoscope, the wind-components are lacking, here and there, for intervals of varying length. Where these components are known for part of a day, the sums have usually been entered in the appropriate columns. The following is a full list of these instances, showing the extent of the break in the record for each case.

January 5–6—Components lacking for 18 hours.
May 19–20—Wind components and sunshine record lacking, 20 hours.
June 13—Components lacking, 5 hours.
July—Components lacking for parts of the 16th, 18th, 22nd, and 23rd.
August—Components lacking for parts of the 18th, 19th, 20th, and 21st.
September—Components lacking for the 8th, and parts of the 7th and 9th.
November 29—Components lacking for 3 hours.
December—Components lacking for 14 hours of the 1st, for 1 hour of the 8th, for the entire week, 9th to 16th, and for 6 hours of the 30th.

The three columns which terminate the page contain the record of precipitation. Here, the indications of the Quadruple Register and the stick-measurement are compared, and the latter receives the preference in the estimate of quantity.

The "Annual Summary by Months," which directly follows the monthly summaries, is entirely composed of material drawn from the latter. If, therefore, any question can arise as to the meaning of any of the entries, it can be solved by reference to the preceding pages.

As in previous years, the record for the four months of January, April, July, and October, are subjected to further analysis for the purpose of tracing the diurnal variation in the chief meteorological elements. For reasons which will be apparent to the reader of the foregoing references to the sunshine record, the latter has not been deemed of sufficiently clear significance to be admitted in the same form heretofore employed, but its place has been taken by a table of the relative cloudiness at the three daily observations, extending through the twelve months. The thermometric columns have been taken from the record of the Richard thermograph, which was continuous through each of the four months discussed. The barometric record was from the Draper barograph, except for January and for short intervals in April and October. In these last, the gaps were filled by aid of the Richard barograph, using the indications of the Draper instrument for the beginning and end of each as fixed points, and the Richard record as showing the differential variations in the passage from one to the other. In January, the gaps in the Draper register were more serious, while that of the Richard instrument was continuous; it was therefore decided to depend upon the latter for the entire record, but to apply a constant correction so as to reduce the readings to values agreeing in the mean with those which the Draper barograph would have supplied. To determine this uniform correction, means were taken for ten days in different parts of the month

where the records of both instruments were continuous. The fact was thus made apparent that in January,—and as further investigation showed, in other months as well,—the average readings of the Draper instrument showed an excess over the other, larger than could be explained from the difference of elevation of their respective exposures at the Observatory and Hagerman Hall. A difference, not quite so great, appeared also between the 12 M. eye-observation of the mercury column, and the mean of the Draper readings for the same hour, amounting in the mean of the four months discussed to 0.109 inch, while the difference of elevation is but 43.2 feet.

In an examination of the meteorological record of 1907 as a whole, the reader will notice a number of points of more or less interest, as distinguishing it from that of other years in this place, or as bringing into prominence certain characters of the Colorado climate illustrated in other years as well. It may not be amiss to call attention to a few of these, particularly in the temperature record. For this year, no temperature below zero has been observed,—an unusual fact, and in marked contrast to the record of 1905, when the yearly minimum was -22°. The mean temperature of the whole year exceeds that of 1905 by 2°.1. In this year, the hottest day and highest monthly mean belong to July, which in both respects exhibits a marked prominence over either June or August, though each of these has successfully rivalled it in other years.

The warm weather of January, February, and March was succeeded by such cold in the latter part of April that the monthly mean for this month actually fell below that of the preceding; yet in consequence of a few high temperatures near the beginning of April, it was true of the days in May that on none of them down to the 20th, had the thermometer risen so high as on some April day preceding it by as much as a whole month. The latest fall of snow was on May 14th. Thus while a Colorado winter may occasionally maintain a

consistent mildness through its whole proper term, it is apt to reappear for a while in the spring with a show of fangs quite disconcerting, especially to the too trustful cultivator of an orchard or a market garden. The monthly range of temperature was not less than 63° in February, March April, or May.

The precipitation for the year has been very light, amounting to 9.80 inches, or little more than two-thirds the ordinary fall. That of the three preceding years has averaged 16.65 inches.

The total movement of wind during 1907 was 70,827 miles, averaging 194 miles a day, or 8.085 miles an hour,—a little larger than in either of the two years just preceding, but not so great as in 1904.

The tri-daily observations, with the care of all the instruments, have been during this year in charge of the same observers who performed the duty in 1906,—Messrs. C. M. Angell, S. L. Smith, and T. D. Riggs.

Hour Ending	January.		April.		July.		October.	
	Barometer.	Thermometer	Barometer.	Thermometer	Barometer.	Thermometer	Barometer.	Thermometer
1 A.M.	24.042	27.5	24.109	38.3	24.247	59.7	24.267	42.1
2 "	.039	26.9	.101	37.7	.244	58.9	.264	41.4
3 "	.035	26.7	.098	37.1	.241	57.8	.258	41.1
4 "	.022	26.8	.097	36.6	.243	56.7	.262	41.1
5 "	.014	26.3	.099	36.0	.247	56.4	.266	40.6
6 "	.016	26.4	.108	35.7	.250	57.7	.269	40.5
7 "	.025	26.7	.113	36.8	.254	62.0	.276	41.4
8 "	.035	26.8	.110	39.3	.255	66.6	.284	46.0
9 "	.050	28.5	.109	42.0	.252	69.7	.286	51.1
10 "	.059	32.4	.107	44.6	.249	72.1	.283	55.6
11 "	.054	36.2	.097	46.0	.243	74.0	.273	57.4
12 M.	.034	38.7	.089	48.1	.235	74.9	.260	59.2
1 P.M.	.010	40.4	.074	49.8	.222	75.3	.239	60.3
2 "	.001	41.6	.064	50.8	.215	75.5	.229	60.9
3 "	.006	42.2	.055	51.4	.209	75.1	.226	60.9
4 "	.013	42.3	.055	51.6	.207	74.9	.227	60.1
5 "	.021	41.1	.063	50.7	.209	73.6	.233	58.0
6 "	.034	38.2	.068	49.6	.213	71.9	.243	55.1
7 "	.050	35.5	.081	47.4	.218	69.9	.252	52.3
8 "	.057	32.8	.100	45.0	.232	68.1	.262	49.6
9 "	.062	30.9	.112	43.2	.244	66.1	.272	47.8
10 "	.064	29.7	.113	41.2	.250	64.3	.274	45.5
11 "	.065	29.1	.113	40.1	.252	62.5	.274	44.1
12 n't	.061	28.7	.113	38.9	.249	60.8	.270	43.1
Sums	576.869	782.4	578.248	1037.9	581.680	1604.5	582.249	1195.2
Means	24.036	32.6	24.094	43.2	24.237	66.9	24.260	49.8

DIURNAL PERIODICITY OF CLOUDINESS.

MEANS OF TRI-DAILY ESTIMATES OF THE PERCENTAGE OF SKY COVERED.

	January.	February.	March.	April.	May.	June.	July.	August.	Septemb'r	October.	Novem.	Decem.
6 A.M.	33	31	38	51	42	28	28	44	23	22	24	33
12 M.	37	34	37	50	71	35	43	40	29	31	27	30
6 P.M.	26	30	34	56	62	42	56	45	35	26	13	19
Mean.	32	32	36	52	58	35	42	43	29	26	21	27

MONTHLY SUMMARY OF

JANUARY,

DATE.	THERMOMETERS.					PSYCHROMETER.						SUNSHINE I		
	TEMPERATURES.			Hours of Extremes.		Relative Humidity.			Dew-point.			Clouds at Observations	Num Min	
	Mean of 24 hrs.	Extremes.				6 A.M.	12 M.	6 P.M.	6 A.M.	12 M.	6 P.M.		Act-ual.	P si
		Max.	Min.	Max.	Min.									
1	25.2	32	20	5 p.m.	6 a.m.	87	88	80	17	21	25	23	101	5
2	25.4	35	16	1 p.m.	12 n't	79	38	65	22	11	15	12	264	5
3	22.6	36	8	4 p.m.	7 a.m.	80	70	71	4	21	22	6	251	5
4	41.2	55	25	2 p.m.	1 a.m.	81	32	42	27	24	28	10	0	5
5	45.0	58	34	2 p.m.	8 a.m.	64	39	36	29	31	26	7	330	5
6	41.0	53	26	3 p.m.	8 a.m.	73	49	39	26	28	23	9	0	5
7	38.5	50	23	2 p.m.	8 a.m.	81	16	19	26	7	5	1	217	5
8	32.0	42	20	1 p.m.	6 a.m.	77	30	58	18	13	22	12	355	5
9	34.4	51	15	4 p.m.	6 a.m.	100	37	30	17	20	13	0	455	5
10	44.0	54	33	4 p.m.	9 p.m.	19	24	35	6	16	19	2	362	5
11	38.8	44	28	4 p.m.	12 n't	47	27	23	21	12	8	0	486	5
12	32.3	47	18	4 p.m.	4 a.m.	39	33	12	3	13	5	0	453	5
13	39.1	49	26	3 p.m.	3 a.m.	21	12	30	6	1	13	1	465	5
14	21.8	32	14	10 a.m.	12 n't	48	100	100	11	19	16	20	68	5
15	18.5	30	12	4 p.m.	9 a.m.	100	100	88	13	18	19	17	252	5
16	32.1	49	22	2 p.m.	12 n't	60	27	44	18	12	14	16	203	5
17	37.5	54	16	2 p.m.	5 a.m.	55	60	32	12	30	18	7	466	5
18	39.6	51	27	2 p.m.	12 n't	58	32	35	22	22	19	3	386	5
19	26.6	38	14	1 a.m.	12 n't	29	32	30	2	6	4	3	481	5
20	24.8	38	8	3 p.m.	5 a.m.	82	20	49	8	1	13	7	406	5
21	40.4	54	26	4 p.m.	11 p.m.	35	20	23	12	13	10	14	301	5
22	35.0	53	20	4 p.m.	4 a.m.	51	23	28	8	14	11	2	470	5
23	40.0	60	24	4 p.m.	7 a.m.	67	17	25	17	14	10	0	484	5
24	30.9	46	18	12 m.	12 n't	57	25	78	15	10	21	11	453	5
25	12.0	18	8	1 a.m.	12 n't	100	100	93	10	10	9	25	0	5
26	16.7	24	4	2 p.m.	1 a.m.	87	74	100	17	15	18	25	5	5
27	20.5	36	2	12 m.	6 a.m.	88	63	60	4	22	18	6	395	5
28	36.9	55	18	4 p.m.	7 a.m.	87	32	46	18	18	28	9	369	5
29	42.2	50	27	2 p.m.	12 n't	55	47	44	30	29	21	21	340	5
30	34.6	51	19	4 p.m.	8 a.m.	100	61	52	21	32	26	23	101	5
31	40.9	55	28	4 p.m.	8 a.m.	63	31	28	22	20	16	4	471	5
Sums,	1010.5	1400	599	.....	.....	2070	1359	1495	482	523	515	296	....	..
Means,	32.6	45.2	19.3	.....	.....	67	44	48	16	17	17	9	....	..
Perc'g.	.....	.....	.....	.....	.....	....	....	....	....	....	....	32%	....	..

INSTRUMENTAL RECORD.

1907.

	ANEMOMETER AND ANEMOSCOPE.							RAIN GAUGE.			
	WIND.							Hours of Fall.		Total Amount.	Date.
	Total Velocity.	Sum of Components.				Equivalent.		Earliest.	Latest.		
		N.	S.	W.	E.	Direction.	Miles.				
2	140	52.5	5.7	82.1	35.3	N. 45° 0′ W.	66.2	10 a.m.	2 p.m.	.10	1
1	239	41.4	68.6	128.2	63.3	S. 67° 16′ W.	70.3	0	0	0	2
2	146	3.9	93.7	10.0	89.2	S. 41° 25′ E.	119.7	7 a.m.	9 a.m.	T	3
2	98	64.7	18.5	26.6	9.5	N. 20° 18′ W.	49.3	0	0	0	4
0	[655]	28.1	74.4	18.0	42.0	S. 27° 24′ E.	52.2	0	0	0	5
8	[ ]	0	172.0	34.4	22.9	S. 3° 50′ W.	172.3	0	0	0	6
3	292	58.6	63.3	182.0	47.8	S. 88° 0′ W.	134.3	8 a.m.	10 a.m.	T	7
4	166	54.0	85.3	8.1	66.1	S. 61° 39′ E.	65.9	0	0	0	8
7	178	87.8	29.3	95.8	20.1	N. 52° 18′ W.	95.6	0	0	0	9
7	240	105.2	55.0	131.8	33.2	N. 63° 01′ W.	110.6	0	0	0	10
6	431	227.6	2.5	349.0	2.1	N. 57° 01′ W.	413.5	0	0	0	11
6	171	64.7	39.6	67.0	40.0	N. 46° 56′ W.	36.9	0	0	0	12
4	264	47.4	129.2	76.6	70.7	S. 4° 07′ W.	82.0	0	0	0	13
0	157	42.6	78.7	12.2	76.8	S. 60° 49′ E.	74.0	0	0	0	14
5	82	20.9	43.9	12.0	30.8	S. 39° 26′ E.	29.7	8 a.m.	.....	T	15
8	127	102.9	9.0	23.5	20.2	N. 2° 02′ W.	93.0	0	0	0	16
1	235	43.0	88.5	108.2	50.0	S. 51° 59′ W.	73.8	0	0	0	17
7	264	36.1	183.3	49.5	54.5	S. 1° 57′ E.	147.2	0	0	0	18
1	465	309.0	34.1	257.5	39.0	N. 38° 29′ W.	351.1	0	0	0	19
1	153	63.2	53.1	24.1	54.3	N. 71° 30′ E.	31.8	0	0	0	20
1	118	42.1	44.8	11.0	53.6	S. 86° 22′ E.	42.6	0	0	0	21
4	140	112.6	15.3	2.8	22.3	N. 11° 20′ E.	99.2	0	0	0	22
5	168	134.6	19.3	18.2	19.5	N. 0° 39′ E.	115.3	0	0	0	23
2	242	77.0	115.6	1.9	118.0	S. 71° 37′ E.	122.3	0	0	0	24
7	146	6.6	108.7	1.9	81.3	S. 37° 52′ E.	129.3	7 a.m.	5 p.m.	.01	25
8	236	151.2	52.7	27.3	67.5	N. 22° 12′ E.	106.4	.....	.....	T	26
7	103	24.3	59.4	3.7	46.3	S. 50° 31′ E.	55.2	0	0	0	27
8	120	41.3	52.5	28.3	26.0	S. 6° 12′ W.	21.3	0	0	0	28
2	191	31.9	101.8	36.8	90.5	S. 37° 32′ E.	88.1	0	0	0	29
5	64	11.2	33.9	0	42.4	S. 61 °50′ E.	48.1	0	0	0	30
4	151	72.3	43.9	50.5	27.7	N. 38° 44′ W.	36.4	0	0	0	31
8	6182	2158.7	1975.6	1879.0	1462.9	.....	.....	.....	.....	0.11	....
2	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
...	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

MONTHLY SUMMARY OF

FEBRUARY,

DATE.	THERMOMETERS.					PSYCHROMETER.						SUNSHINE F		
	TEMPERATURES.			Hours of Extremes.		Relative Humidity.			Dew-point.			Clouds at Observations	Num Min	
	Mean of 24 hrs.	Extremes.				6 A.M.	12 M.	6 P.M.	6 A.M.	12 M.	6 P.M.		Act-ual.	P si
		Max.	Min.	Max.	Min.									
1	45.7	63	26	3 p.m.	12 n't	28	18	17	11	16	11	9	381	5
2	21.2	27	15	4 p.m.	12 n't	100	87	88	18	18	21	19	20	5
3	10.3	19	1	4 p.m.	8 a.m.	95	51	67	3	1	6	14	291	5
4	31.0	55	10	2 p.m.	2 a.m.	47	47	61	21	34	20	13	317	5
5	37.8	53	18	1 p.m.	1 a.m.	64	36	47	29	26	21	14	248	5
6	45.1	56	25	1 p.m.	12 n't	31	19	41	20	16	22	2	525	5
7	35.1	53	20	4 p.m.	7 a.m.	100	27	13	19	18	0	1	447	5
8	51.5	69	29	4 p.m.	1 a.m.	30	7	11	13	1	8	0	494	5
9	42.9	54	26	7 a.m.	12 n't	27	26	51	7	16	25	13	155	5
10	37.3	55	20	4 p.m.	5 a.m.	67	20	15	17	13	4	1	537	5
11	41.0	61	24	3 p.m.	4 a.m.	69	10	23	20	4	14	0	538	5
12	45.7	58	27	3 p.m.	1 a.m.	27	11	16	12	4	8	8	388	5
13	42.5	56	28	2 p.m.	12 n't	51	13	37	20	8	20	0	522	5
14	38.2	56	20	3 p.m.	8 a.m.	77	16	32	18	11	18	4	514	5
15	42.1	56	27	2 p.m.	12 n't	66	14	19	25	8	9	0	593	5
16	39.5	59	22	3 p.m.	4 a.m.	55	9	54	12	1	34	0	525	6
17	44.5	62	25	3 p.m.	4 a.m.	66	23	30	25	22	21	18	449	6
18	44.6	53	35	4 p.m.	8 a.m.	30	33	32	13	23	22	0	489	6
19	45.0	58	28	3 p.m.	3 a.m.	59	22	28	23	18	20	11	483	6
20	45.2	63	27	3 p.m.	7 a.m.	62	12	37	21	7	28	15	473	6
21	34.9	44	26	1 p.m.	7 a.m.	69	65	70	20	30	30	18	206	6
22	41.9	62	23	3 p.m.	4 a.m.	79	31	95	23	27	55	6	476	6
23	44.5	57	32	1 p.m.	3 a.m.	51	40	60	25	27	30	16	242	6
24	37.8	48	28	5 p.m.	12 n't	100	61	60	32	31	30	15	328	6
25	41.1	62	22	1 p.m.	4 a.m.	89	22	25	22	16	18	4	521	6
26	41.9	55	28	2 p.m.	12 n't	34	20	61	15	16	25	10	326	6
27	23.7	28	19	4 p.m.	7 a.m.	100	100	95	21	38	23	30	0	6
28	25.0	32	19	2 p.m.	5 a.m.	73	70	100	14	21	25	27	119	6
Sums,	1077.0	1474	650	.....	.....	1746	981	1285	519	471	568	268	....	.
Means,	38.5	52.6	23.2	.....	.....	62	35	46	19	17	20	10	....	.
Perc'g,	.....	.....	.....	.....	.....	....	.....	.....	.....	....	....	32%	....	.

INSTRUMENTAL RECORD.

1907.

...ure.	Anemometer and Anemoscope.							Rain Gauge.			Date.
	Wind.							Hours of Fall.		Total Amount.	
...ual ...ure 7 A.M.	Total Velocity.	Sum of Components.				Equivalent.		Earliest.	Latest.		
		N.	S.	W.	E.	Direction.	Miles.				
.715	296	139.1	43.8	197.1	20.0	N. 61° 43′ W.	201.1	0.	0	0	1
.933	50	18.1	22.6	1.7	21.8	S. 77° 23′ E.	20.6	6 a.m.	12 m.	.02	2
.939	70	0	53.4	0.9	41.9	S. 37° 31′ E.	67.3	0	0	0	3
.800	253	93.5	77.1	121.0	59.8	N. 75° 00′ W.	63.3	0	0	0	4
.926	165	41.6	80.9	14.7	80.1	S. 59° 02′ E.	76.3	0	0	0	5
.030	314	228.1	24.9	106.1	36.9	N. 18° 48′ W.	214.7	0	0	0	6
.318	155	101.0	37.4	8.1	37.8	N. 25° 02′ E.	70.2	0	0	0	7
.196	276	178.6	12.7	170.5	3.8	N. 45° 08′ W.	235.2	0	0	0	8
.288	251	231.5	0	15.7	59.2	N. 10° 39′ E.	235.5	0	0	0	9
.339	162	112.0	37.2	5.6	30.8	N. 18° 37′ E.	78.9	0	0	0	10
.248	198	118.0	53.0	24.8	48.9	N. 20° 21′ E.	69.3	0	0	0	11
.090	301	209.6	0	202.9	0	N. 44° 04′ W.	291.7	0	0	0	12
.222	150	89.3	30.1	17.2	58.7	N. 35° 02′ E.	72.3	0	0	0	13
.318	141	100.4	23.2	10.2	32.7	N. 16° 15′ E.	80.4	0	0	0	14
.269	189	135.8	35.2	26.8	34.8	N. 4° 33′ E.	100.9	0	0	0	15
.192	177	128.7	27.9	16.4	36.3	N. 11° 10′ E.	102.7	0	0	0	16
.957	237	180.1	8.0	123.1	7.2	N. 33° 57′ W.	207.5	0	0	0	17
.953	317	195.8	41.8	128.1	40.3	N. 29° 41′ W.	177.3	0	0	0	18
.000	183	111.8	36.3	55.0	36.2	N. 13° 59′ W.	77.8	0	0	0	19
.899	220	176.9	0	90.0	13.5	N. 23° 23′ W.	192.7	0	0	0	20
.964	136	31.3	72.2	2.7	73.9	S. 60° 08′ E.	82.1	0	0	0	21
.884	130	50.6	31.7	45.1	45.1	North	18.9	0	0	0	22
.916	236	172.0	17.6	82.0	12.0	N. 24° 23′ W.	169.6	0	0	0	23
.306	217	35.9	122.6	5.8	131.6	S. 58° 38′ E.	147.2	.....	.....	.06	24
.955	164	70.3	68.0	10.4	55.5	N. 87° 05′ E.	45.2	0	0	0	25
.810	189	64.1	69.4	16.2	85.7	S. 85° 38′ E.	69.7	0	0	0	26
.705	197	58.0	103.9	0.8	92.8	S. 63° 29′ E.	102.8	8 a.m.	4 p.m.	T	27
.891	138	128.9	0	8.9	23.2	N. 6° 20′ E.	129.7	4 p.m.	.....	.03	28
.163	5512	3201.0	1130.9	1507.8	1220.5	.....	.....	.....	.....	.....	....
.042	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.11	....
.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	....

MONTHLY SUMMARY OF

MARCH,

DATE.	THERMOMETERS.					PSYCHROMETER.						SUNSHINE R	
	TEMPERATURES.			Hours of Extremes.		Relative Humidity.			Dew-point.			Clouds at Observations	Numb Minu
	Mean of 24 hrs.	Extremes.				6 A.M.	12 M.	6 P.M.	6 A.M.	12 M.	6 P.M.		Act-ual.	Pos-sible
		Max.	Min.	Max.	Min.									
1	35.5	52	13	5 p.m.	7 a.m.	85	34	24	13	17	14	11	222	640
2	47.9	56	35	4 p.m.	12 n't	31	23	38	16	18	26	2	544	642
3	42.6	62	22	4 p.m.	7 a.m.	77	22	22	20	18	18	7	502	644
4	45.0	59	31	1 p.m.	12 n't	67	18	49	26	16	28	17	310	647
5	32.2	41	25	4 p.m.	4 a.m.	89	74	70	26	27	29	25	96	649
6	44.3	58	30	3 p.m.	1 a.m.	83	31	21	31	23	12	7	514	652
7	39.7	50	24	1 p.m.	8 a.m.	77	45	47	20	26	29	6	492	655
8	41.0	59	21	4 p.m.	7 a.m.	93	33	27	22	23	18	1	554	658
9	37.5	47	29	1 p.m.	12 n't	67	41	67	26	22	26	18	255	660
10	39.9	57	25	6 p.m.	8 a.m.	89	47	68	23	25	46	9	448	662
11	47.9	57	36	1 p.m.	3 a.m.	24	54	38	16	34	26	9	446	664
12	32.6	44	25	4 p.m.	12 n't	90	100	67	28	31	26	27	91	666
13	24.9	31	17	6 p.m.	7 a.m.	86	78	79	16	21	24	18	334	668
14	34.5	51	15	5 p.m.	6 a.m.	75	29	32	16	14	18	1	580	671
15	41.6	56	25	3 p.m.	7 a.m.	41	23	25	10	14	18	19	350	676
16	51.0	64	39	5 p.m.	1 a.m.	40	25	48	25	24	36	8	412	681
17	54.5	69	38	4 p.m.	7 a.m.	51	28	17	24	30	21	8	443	683
18	57.9	78	35	5 p.m.	7 a.m.	75	16	23	29	25	33	19	480	686
19	63.2	77	46	4 p.m.	7 a.m.	56	16	24	37	25	32	19	461	687
20	60.5	74	42	1 p.m.	3 a.m.	45	36	30	26	44	36	15	402	689
21	61.2	70	44	3 p.m.	12 n't	58	23	52	47	28	47	5	470	692
22	54.0	65	40	3 p.m.	1 a.m.	67	53	67	42	44	42	18	463	694
23	50.7	63	34	4 p.m.	6 a.m.	91	49	52	32	37	42	1	522	695
24	55.9	70	39	1 p.m.	3 a.m.	60	28	38	30	33	37	0	594	697
25	59.1	70	51	3 p.m.	6 a.m.	62	23	55	41	28	47	8	472	698
26	56.8	66	50	3 p.m.	7 a.m.	26	22	39	20	24	34	8	551	700
27	44.8	60	27	4 p.m.	7 a.m.	79	45	31	24	35	27	5	529	702
28	35.5	41	29	4 p.m.	6 a.m.	80	82	54	25	28	23	22	51	705
29	40.2	51	30	4 p.m.	7 a.m.	82	48	43	30	26	23	12	380	710
30	31.2	51	25	5 p.m.	6 a.m.	79	36	33	23	23	13	7	476	715
31	42.0	58	20	5 p.m.	6 a.m.	87	36	40	17	26	32	4	483	718
Sums,	1405.6	1807	962	.....	.....	2112	1218	1320	781	809	883	336	....	....
Means,	45.3	58.3	31.0	.....	.....	68	39	43	25	26	28	11	....	....
Perc'g,	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	36%	....	....

INSTRUMENTAL RECORD.

1907.

Barometer.	Anemometer and Anemoscope. Wind. Total Velocity.	Sum of Components. N.	S.	W.	E.	Equivalent. Direction.	Miles.	Rain Gauge. Hours of Fall. Earliest.	Latest.	Total Amount.	Date.
012	224	77.4	47.1	134.4	24.0	N. 74° 39′ W.	114.5	.....	.....	.02	1
095	381	214.1	7.5	285.5	11.5	N. 53° 01′ W.	343.4	0	0	0	2
958	161	66.8	49.0	53.7	34.0	N. 47° 54′ W.	26.5	0	0	0	3
975	183	46.5	69.4	17.5	107.1	S. 75° 40′ E.	92.5	0	0	0	4
107	139	0	97.5	0	98.7	S. 45° 21′ E.	138.7	0	0	0	5
876	375	200.1	11.1	273.0	14.5	N. 53° 50′ W.	320.2	0	0	0	6
068	192	21.5	134.3	6.5	84.5	S. 34° 42′ E.	137.1	0	0	0	7
955	185	63.2	79.0	35.2	63.2	S. 60° 34′ E.	32.1	0	0	0	8
964	343	301.9	18.3	31.6	53.1	N. 4° 20′ E.	284.4	5 p.m.	.....	T	9
050	162	35.3	70.2	9.1	99.4	S. 68° 52′ E.	96.8	.....	7 a.m.	T	10
765	466	34.6	139.1	408.1	6.3	S. 75° 25′ W.	415.1	0	0	0	11
024	225	137.9	59.8	7.8	83.0	N. 43° 55′ E.	108.4	10 p.m.	.....	....	12
876	175	98.9	56.5	4.2	50.9	N. 47° 46′ E.	63.1	.....	.....	.14	13
059	174	76.9	49.9	58.6	35.8	N. 62° 55′ W.	59.3	0	0	0	14
009	149	58.3	73.6	11.2	32.0	S. 53° 40′ E.	25.8	0	0	0	15
012	193	80.9	67.3	51.4	51.5	N. 0 25′ E.	13.6	0	0	0	16
067	181	24.7	107.8	35.2	71.0	S. 23° 18′ E.	90.5	0	0	0	17
015	197	62.8	52.4	82.8	40.8	N. 76° 05′ W.	43.3	0	0	0	18
114	195	48.8	48 4	100.0	44.4	N. 89° 35′ W.	55.6	0	0	0	19
953	227	54.5	151.3	36.6	39.7	S. 1° 50′ E.	96.9	0	0	0	20
822	319	17.0	149.1	210.8	41.4	S. 52° 03′ W.	214.8	0	0	0	21
784	280	40.0	155.2	39.1	126.0	S. 37° 02′ E.	144.3	0	0	0	22
995	238	27.7	158.2	47.8	77.6	S. 12° 52′ E.	133.8	0	0	0	23
850	248	58.3	109.3	106.6	50.3	S. 47° 50′ W.	76.0	0	0	0	24
745	321	21.5	179.6	46.8	174.8	S. 39° 00′ E.	203.4	0	0	0	25
535	571	0	408.0	338.1	36.6	S. 36° 28′ W.	507.2	0	0	0	26
770	268	67.9	160.8	40.0	70.6	S. 18° 14′ E.	97.7	0	0	0	27
778	170	119.0	0	94.4	13.0	N. 34° 22′ W.	144.2	7 a.m.	2 p.m.	T	28
050	320	109.8	104.6	152.4	60.3	N. 86° 46′ W.	92.2	0	0	0	29
290	167	100.9	27.3	28.0	59.1	N. 22° 55′ E.	79.9	0	0	0	30
273	203	35.7	112.4	7.0	114.7	S. 54° 33′ E.	132.2	0	0	0	31
536	7632	2302.9	2954.0	2753.4	1869.8	.....	.....	.....	0	.16	....
953	.....	.....	.....	.....	.....	.....	.....	.....	.....	....	....
....	.....	.....	.....	.....	.....	.....	.....	.....	.....	....	....

MONTHLY SUMMARY OF

APRIL,

DATE.	THERMOMETERS.					PSYCHROMETER.						SUNSHINE R		
	TEMPERATURES.			Hours of Extremes.		Relative Humidity.			Dew-point.			Clouds at Observations	Numb Minu	
	Mean of 24 hrs.	Extremes.				6 A.M.	12 M.	6 P.M.	6 A.M.	12 M.	6 P.M.		Act-ual.	Pos-sibl
		Max.	Min.	Max.	Min.									
1	54.8	69	37	2 p.m.	1 a.m.	61	29	58	31	32	48	22	295	72
2	57.7	68	48	4 p.m.	3 a.m.	56	43	33	37	41	33	11	461	72
3	52.9	63	44	3 p.m.	7 a.m.	48	28	38	31	27	29	9	405	72
4	39.9	50	35	4 p.m.	12 n't	92	52	67	35	26	33	21	257	73
5	43.1	59	31	5 p.m.	6 a.m.	91	49	71	30	28	42	24	252	73
6	47.1	54	38	1 p.m.	7 a.m.	55	46	28	24	33	42	12	485	73
7	49.2	58	35	4 p.m.	12 n't	57	40	47	27	32	34	6	579	73
8	42.8	58	32	4 p.m.	7 a.m.	82	46	47	30	32	34	12	381	74
9	54.4	69	39	2 p.m.	1 a.m.	72	19	26	34	23	27	7	546	74
10	62.5	78	42	4 p.m.	6 a.m.	55	18	21	30	29	30	15	419	74
11	51.2	60	40	4 p.m.	7 a.m.	86	61	53	37	39	38	11	438	75
12	43.0	52	32	4 p.m.	6 a.m.	73	38	36	26	22	23	4	530	75
13	43.4	55	29	5 p.m.	7 a.m.	71	42	37	22	28	28	22	160	75
14	55.8	75	31	3 p.m.	6 a.m.	66	22	15	25	29	19	4	611	75
15	52.2	61	44	1 p.m.	5 a.m.	49	14	48	32	17	36	16	321	76
16	38.4	46	28	5 p.m.	12 n't	75	57	53	28	27	28	13	226	76
17	45.5	67	24	2 p.m.	5 a.m.	49	25	24	22	25	24	11	452	76
18	33.0	40	30	11 a.m.	12 n't	71	75	91	22	28	30	23	25	76
19	27.2	30	22	1 a.m.	1 p.m.	89	77	77	26	20	20	30	0	77
20	22.2	26	17	2 p.m.	12 n't	97	88	88	19	20	19	30	388	77
21	25.0	32	12	4 p.m.	6 a.m.	83	90	70	10	28	21	3	598	77
22	44.4	61	26	1 p.m.	1 a.m.	56	29	47	20	23	34	1	552	77
23	52.8	64	40	5 p.m.	1 a.m.	78	18	28	26	18	27	2	529	78
24	45.5	60	26	11 a.m.	12 n't	56	48	92	31	36	35	22	191	78
25	25.9	31	20	9 p.m.	8 a.m.	88	88	100	19	21	30	30	102	78
26	44.3	64	26	4 p.m.	6 a.m.	89	51	50	26	40	38	15	343	79
27	47.5	65	34	3 p.m.	6 a.m.	75	41	70	29	37	39	13	358	79
28	42.6	61	30	1 p.m.	12 n't	100	45	75	34	41	39	22	279	79
29	26.1	30	23	1 a.m.	12 n't	75	79	100	17	24	25	30	0	79
30	27.2	33	22	1 p.m.	2 a.m.	88	90	90	21	29	28	30	28	80
Sums,	1297.6	1639	937	.....	.....	2183	1448	1680	801	855	933	471	....	....
Means,	43.2	54.6	31.2	.....	.....	73	48	56	27	28	31	16	....	....
Perc'g,	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	52%	....	....

INSTRUMENTAL RECORD.

1907.

...ROM-ER.	ANEMOMETER AND ANEMOSCOPE.							RAIN GAUGE.			Date.
	WIND.							Hours of Fall.		Total Amount.	
...tual ...sure 12 M.	Total Velocity.	Sum of Components. N.	S.	W.	E.	Equivalent. Direction.	Miles.	Earliest.	Latest.		
.033	141	46.8	52.0	64.6	22.4	S. 82° 58′ W.	42.5	0	0	0	1
.953	226	71.5	64.2	151.4	10.9	N. 87° 02′ W.	140.7	0	0	0	2
.908	340	211.4	48.7	159.8	37.4	N. 36° 57′ W.	203.6	10 p.m.	.....	....	3
.068	262	181.6	31.4	95.9	43.1	N. 2° 01′ W.	159.2	.....	7 a.m.	.44	4
.807	113	44.6	43.2	31.5	23.8	N. 79° 42′ W.	7.8	0	0	0	5
.727	329	218.8	9.1	117.8	37.3	N. 20° 53′ W.	224.4	0	0	0	6
.824	588	415.3	0	390.4	9.1	N. 42° 29′ W.	563.1	0	0	0	7
.171	148	29.9	73.0	2.8	98.4	S. 65° 44′ E.	104.9	0	0	0	8
.059	140	27.5	76.5	7.4	78.1	S. 55° 16′ E.	86.0	0	0	0	9
.989	261	138.3	21.3	154.9	33.7	N. 46° 00′ W.	168.5	0	0	0	10
.085	253	117.3	95.1	4.4	95.5	N. 76° 18′ E.	93.9	0	0	0	11
.191	195	2.4	127.5	0	140.4	S. 48° 18′ E.	188.0	0	0	0	12
.073	94	24.7	37.8	16.1	26.8	S. 39° 14′ E.	16.9	0	0	0	13
.867	260	135.2	26.7	137.5	22.4	N. 46° 41′ W.	158.2	0	0	0	14
.968	288	73.7	157.2	5.3	150.9	S. 60° 10′ E.	167.9	0	0	0	15
.106	243	0	141.2	0	180.5	S. 51° 58′ E.	229.1	0	0	0	16
.784	317	179.0	56.3	114.2	52.7	N. 26° 37′ W.	137.3	0	0	0	17
.002	163	78.2	60.4	5.9	47.9	N. 67° 58′ W.	45.4	.....	.....	.07	18
.972	324	212.5	74.3	81.1	87.9	N. 2° 49′ E.	138.3	.....	.....	.08	19
.267	137	77.6	6.8	12.4	68.7	N. 38° 25′ E.	90.5	.....	.....	.69	20
.144	103	27.7	40.3	24.1	39.9	S. 51° 26′ E.	20.2	.....	.....	T	21
.954	243	224.7	0	16.9	35.1	N. 4° 38′ E.	225.4	0	0	0	22
.930	165	51.2	82.8	35.4	47.5	S. 20° 57′ E.	33.8	0	0	0	23
.853	282	241.7	17.9	23.1	45.1	N. 5° 37′ E.	224.9	.....	.....	.01	24
.027	235	76.6	124.2	0.3	102.2	S. 64° 58′ E.	112.5	.....	.....	.07	25
.869	176	39.5	106.4	18.0	72.0	S. 14° 14′ E.	69.2	.....	5 p.m.	T	26
.913	211	123.7	46.7	41.2	58.7	N. 43° 15′ E.	106.7	0	0	0	27
.852	217	145.8	37.7	6.9	80.0	N. 34° 04′ E.	130.5	.....	.....	T	28
.021	262	140.5	86.3	0	103.7	N. 62° 24′ E.	117.0	.....	.....	.16	29
.054	125	4.8	83.3	0	84.2	S. 47° 00′ E.	115.1	.....	5 p.m.	.06	30
.371	6841	3441.0	1828.3	1720.3	1936.3	.....	.....	.....	.....	1.58	....
.979	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	....
.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	....

MONTHLY SUMMARY OF

MAY,

DATE.	THERMOMETERS.					PSYCHROMETER.						SUNSHINE REC		
	TEMPERATURES.			Hours of Extremes.		Relative Humidity.			Dew-point.			Clouds at Observations	Number Minut	
	Mean of 24 hrs.	Extremes. Max.	Extremes. Min.	Max.	Min.	6 A.M.	12 M.	6 P.M.	6 A.M.	12 M.	6 P.M.		Actual.	Possible
1	35.6	46	27	4 p.m.	6 a.m.	100	85	85	28	35	35	28	171	803
2	31.5	42	24	11 a.m.	12 n't	82	91	89	28	32	24	19	196	804
3	31.2	42	17	5 p.m.	5 a.m.	88	91	77	19	32	32	21	0	807
4	36.2	49	29	9 a.m.	5 a.m.	100	77	92	29	32	34	26	11	808
5	34.5	41	31	3 p.m.	12 n't	100	100	100	32	35	36	30	0	810
6	38.1	49	31	3 p.m.	1 a.m.	100	73	86	33	36	39	30	0	813
7	42.2	52	36	10 a.m.	6 a.m.	76	64	80	31	37	38	26	65	816
8	45.0	53	33	3 p.m.	6 a.m.	100	70	64	36	39	37	14	215	819
9	47.8	59	35	12 m.	6 a.m.	85	54	61	34	39	40	14	206	822
10	54.5	67	37	3 p.m.	5 a.m.	72	50	50	34	44	44	1	590	824
11	60.4	74	40	5 p.m.	3 a.m.	75	40	55	39	43	54	10	387	827
12	59.6	66	43	1 p.m.	12 n't	51	33	39	40	35	34	10	405	829
13	36.0	44	30	1 a.m.	12 n't	84	91	74	32	30	27	23	143	832
14	35.1	47	26	2 p.m.	5 a.m.	79	47	69	24	25	28	20	120	833
15	49.1	62	28	3 p.m.	3 a.m.	77	48	48	32	40	40	11	502	834
16	59.9	75	43	5 p.m.	6 a.m.	55	30	44	35	36	47	6	656	835
17	62.3	73	49	12 m.	3 a.m.	62	42	22	41	47	29	11	448	836
18	57.5	64	49	5 p.m.	6 a.m.	61	41	63	40	38	50	21	336	837
19	57.5	69	46	2 p.m.	5 a.m.	100	37	47	47	26	43	17	459	839
20	61.3	78	45	5 p.m.	4 a.m.	88	29	22	45	41	31	14	....	840
21	64.0	80	48	3 p.m.	3 a.m.	55	16	29	41	28	36	17	337	841
22	63.4	76	49	12 m.	4 a.m.	71	17	23	41	27	33	13	257	843
23	58.3	73	48	12 m.	3 a.m.	77	24	46	45	34	42	17	318	845
24	53.3	58	43	12 m.	3 a.m.	33	32	59	23	24	35	13	258	846
25	43.7	52	36	10 a.m.	5 a.m.	86	58	80	36	34	39	20	150	848
26	41.7	47	35	4 p.m.	5 a.m.	80	53	55	39	29	30	19	40	849
27	41.9	55	37	4 p.m.	6 a.m.	55	42	51	24	28	36	19	157	851
28	46.2	53	41	12 m.	5 a.m.	67	56	75	33	38	39	22	0	852
29	46.8	53	41	4 p.m.	4 a.m.	42	65	70	26	39	39	12	275	854
30	43.3	46	40	2 p.m.	12 n't	58	80	79	28	38	37	26	3	855
31	47.0	58	34	2 p.m.	5 a.m.	84	39	43	33	31	31	12	226	856
Sums,	1484.9	1803	1151	.....	.....	2343	1675	1877	1048	1072	1139	542	....	....
Means,	47.9	58.2	37.1	.....	.....	76	54	61	32	35	37	17	....	....
Perc'g,	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	58%	....	....

*For 30 d

INSTRUMENTAL RECORD.

1907.

...M-ER.	ANEMOMETER AND ANEMOSCOPE. WIND.							RAIN GAUGE.			
		Sum of Components.				Equivalent.		Hours of Fall.		Total Amount.	Date.
...al ...ure ...M.	Total Velocity.	N.	S.	W.	E.	Direction.	Miles.	Earliest.	Latest.		
.065	150	25.8	90.1	22.2	67.0	S. 34° 52′ E.	78.3	5 p.m.	5 p.m.	T	1
.062	279	275.1	0	8.2	25.3	N. 31° 52′ E.	32.4	12 m.	7 p.m.	.32	2
.178	224	50.6	122.7	1.7	120.3	S. 58° 40′ E.	138.6	0	0	0	3
.946	240	209.3	12.9	2.9	49.7	N. 13° 24′ E.	201.9	6 p.m.	.....	T	4
.926	128	2.7	92.3	0	83.6	S. 43° 01′ E.	122.5	.....	.....	.16	5
.925	101	29.5	31.0	9.6	62.8	S. 88° 23′ E.	53.2	.....	5 p.m.	.32	6
.957	172	85.8	38.4	59:6	33.5	N. 28° 50′ W.	54.1	11 a.m.	.....	T	7
.000	135	43.0	54.0	58.8	22.6	S. 73° 06′ W.	37.8	.....	1 p.m.	.02	8
.071	136	73.6	31.9	30.8	28.0	N. 3° 50′ W.	41.9	1 p.m.	2 p.m.	.20	9
.095	193	76.4	87.7	1.2	77.8	S. 81° 36′ E.	77.4	0	0	0	10
.835	157	38.9	97.1	31.5	27.5	S. 3° 56′ W.	58.3	0	0	0	11
.486	347	39.9	252.9	121.1	36.4	S. 21° 41′ W.	229.2	0	0	0	12
.835	452	433.6	0	50.3	32.3	N. 2° 23′ W.	434.0	7 a.m.	.....	T	13
.987	290	264.7	3.6	22.6	51.1	N. 6° 14′ E.	262.6	4 p.m.	.....	T	14
.067	364	317.3	0	118.9	13.8	N. 18° 19′ W.	334.3	.....	8 a.m.	T	15
.079	178	105.1	34.5	54.9	31.8	N. 18° 07′ W.	74.3	0	0	0	16
.032	163	91.2	45.4	54.3	16.6	N. 39° 28′ W.	59.3	0	0	0	17
.109	227	71.1	109.0	28.4	92.6	S. 59° 27′ E.	74.5	.....	.....	....	18
.130	[378]	14.3	81.2	4.5	55.1	S. 37° 06′ E.	83.9	.....	.....	.11	19
.006	[ ]	21.1	40.3	66.8	8.3	S. 71° 50′ W.	61.6	.....	.....	T	20
.002	185	82.8	33.6	79.3	33.8	N. 35° 49′ W.	60.7	.....	6 p.m.	T	21
.962	149	61.7	51.5	59.4	13.5	N. 77° 28′ W.	47.0	0	0	0	22
.856	191	82.9	79.6	15.0	68.1	N. 86° 27′ E.	53.2	5 p.m.	5 p.m.	T	23
.806	264	204.7	0	63.3	66.5	N. 0° 54′ E.	204.7	0	0	0	24
.851	203	144.7	32.7	9.3	60.4	N. 24° 32′ E.	123.1	12 m.	.....	.16	25
.220	300	282.9	1.0	7.2	60.3	N. 10° 40′ E.	286.9	0	0	0	26
.084	264	12.9	184.1	0	170.3	S. 44° 51′ E.	241.5	0	0	0	27
.802	212	178.8	24.0	12.6	24.9	N. 4° 33′ E.	155.3	1 p.m.	.....	.25	28
.891	350	335.8	0	19.0	56.1	N. 6° 18′ E.	337.8	0	0	0	29
.026	250	244.2	0	24.7	14.2	N. 2° 28′ W.	244.3	.....	.....	.11	30
.103	190	156.4	0	65.7	33.0	N. 11° 49′ W.	159.7	0	0	0	31
.394	6872	.....	.....	.....	.....	.....	.....	.....	.....	1.65	....
.980	.....	4056.8	1631.5	1103.8	1537.2	.....	.....	.....	.....	....	....
....	.....	.....	.....	.....	.....	.....	.....	.....	.....	....	....

MONTHLY SUMMARY OF

JUNE,

DATE.	THERMOMETERS.					PSYCHROMETER.						SUNSHINE RE		
	TEMPERATURES.			Hours of Extremes.		Relative Humidity.			Dew-point.			Clouds at Observations	Numbe Minut	
	Mean of 24 hrs.	Extremes. Max.	Extremes. Min.	Max.	Min.	6 A.M.	12 M.	6 P.M.	6 A.M.	12 M.	6 P.M.		Act-ual.	Pos sibl
1	53.5	67	37	4 p.m.	5 a.m.	67	33	32	33	33	33	0	551	856
2	58.5	67	41	5 p.m.	4 a.m.	47	40	42	32	40	43	16	195	857
3	56.9	72	46	3 p.m.	5 a.m.	46	41	28	28	42	33	9	504	857
4	58.4	72	44	1 p.m.	5 a.m.	64	33	34	37	38	37	6	399	859
5	57.3	68	49	1 p.m.	6 a.m.	88	53	63	47	49	50	21	368	859
6	60.5	75	47	4 p.m.	5 a.m.	54	18	57	34	26	51	13	400	860
7	59.7	71	41	2 p.m.	5 a.m.	60	36	58	38	41	54	8	372	861
8	59.9	72	47	3 p.m.	2 a.m.	58	9	15	42	10	19	10	575	862
9	54.9	64	40	5 p.m.	5 a.m.	28	51	21	20	40	24	12	279	863
10	58.2	69	45	4 p.m.	5 a.m.	55	24	28	35	26	33	3	433	863
11	61.9	78	42	2 p.m.	5 a.m.	41	14	25	26	24	34	9	447	863
12	65.1	80	44	3 p.m.	5 a.m.	49	10	16	32	18	25	2	616	863
13	66.9	78	50	5 p.m.	5 a.m.	50	11	11	33	18	21	1	610	863
14	67.8	79	51	3 p.m.	5 a.m.	26	10	13	22	18	22	0	604	863
15	66.1	82	44	3 p.m.	5 a.m.	19	12	18	11	23	29	3	493	863
16	62.5	75	52	11 a.m.	5 a.m.	27	36	44	23	38	42	24	8	863
17	61.5	71	48	2 p.m.	6 a.m.	44	34	34	29	40	40	22	117	863
18	60.2	67	50	3 p.m.	5 a.m.	71	30	37	43	34	39	19	202	863
19	56.9	66	48	3 p.m.	5 a.m.	54	44	34	34	42	37	22	204	863
20	57.3	67	49	3 p.m.	5 a.m.	54	41	43	34	42	41	20	143	863
21	59.3	73	43	1 p.m.	4 a.m.	50	27	37	33	33	39	12	85	863
22	66.2	79	48	5 p.m.	5 a.m.	48	13	15	36	22	23	0	604	863
23	64.5	76	50	4 p.m.	5 a.m.	46	26	21	37	36	32	1	466	863
24	65.6	80	50	2 p.m.	5 a.m.	47	12	31	34	23	44	0	387	863
25	57.2	63	53	3 p.m.	5 a.m.	39	57	70	31	46	50	15	386	863
26	57.0	66	48	12 m.	5 a.m.	65	63	79	39	51	50	19	59	863
27	59.7	70	47	3 p.m.	5 a.m.	72	40	35	44	43	38	12	241	863
28	65.8	81	48	2 p.m.	5 a.m.	73	13	20	46	26	23	11	287	863
29	70.9	87	52	5 p.m.	2 a.m.	45	17	20	41	32	36	6	338	863
30	64.0	75	55	10 a.m.	4 a.m.	56	29	66	49	41	54	19	140	863
Sums,	1834.2	2190	1409	.....	.....	1543	877	1047	1023	995	1096	315	.....	.....
Means,	61.1	73.0	47.0	.....	.....	51	29	35	34	33	37	10	.....	.....
Perc'g,	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	35%	.....	.....

INSTRUMENTAL RECORD.

1907.

BAROMETER.	ANEMOMETER AND ANEMOSCOPE. WIND.							RAIN GAUGE.			
		Sum of Components.				Equivalent.		Hours of Fall.			
Actual Pressure 12 M.	Total Velocity.	N.	S.	W.	E.	Direction.	Miles.	Earliest.	Latest.	Total Amount.	Date.
.080	154	42.7	90.8	9.4	56.5	S. 44° 24′ E.	67.3	0	0	0	1
.929	249	130.6	93.1	23.8	67.9	N. 49° 38′ E.	57.9	1 p.m.	7 p.m.	T	2
.909	280	163.2	45.1	100.7	59.9	N. 19° 03′ W.	125.0	0	0	0	3
.036	154	26.9	72.3	17.7	89.9	S. 58° 01′ E.	85.7	11 p.m.	11 p.m.	T	4
.092	214	2.0	149.4	0	145.1	S. 44° 33′ E.	206.8	10 p.m.	11 p.m.	04	5
.859	151	74.8	18.9	61.7	34.2	N. 26° 12′ W.	62.3	0	0	0	6
.894	220	56 8	126.9	1.6	97.6	S. 53° 52′ E.	118.9	0	0	0	7
.823	303	155.2	109.0	96.5	18.8	N. 59° 16′ W.	90.4	0	0	0	8
.853	256	207.3	17.2	41.0	51.1	N. 3° 02′ E.	190.3	11 a.m.	12 m.	T	9
.039	175	26.0	108.1	12.6	95.5	S. 45° 17′ E.	116.6	0	0	0	10
.986	183	67.5	98.2	18.3	48.7	S. 44° 43′ E.	43.2	0	0	0	11
.848	254	52.4	183.9	51.9	10.5	S. 17° 28′ W.	137.8	0	0	0	12
.906	208	39.9	54.3	15.4	36.1	S. 55° 10′ E.	25.2	0	0	0	13
.902	229	36.4	171.3	23.4	53.2	S. 12° 28′ E.	138.1	0	0	0	14
.934	340	31.3	271.4	1.7	101.6	S. 22° 36′ E.	260.1	0	0	0	15
.130	179	103.7	47.4	18.5	47.7	N. 27° 25′ E.	63.4	0	0	0	16
.276	171	165.7	0	18.1	11.8	N. 2° 11′ W.	165.8	10 p.m.	11 p.m.	10	17
.406	158	60.0	77.7	1.4	61.3	S. 73° 32′ E.	62.4	0	0	0	18
.172	208	5.9	134.5	37.8	102.0	S. 26° 32′ E.	143.7	0	0	0	19
.995	101	16.2	49.4	8.7	56.8	S. 55° 23′ E.	58.4	0	0	0	20
.912	171	93.5	18.3	61.2	46.0	N. 11° 26′ W.	76.7	.....	.....	04	21
.860	200	40.7	131.7	70.6	17.6	S. 30° 13′ W.	105.3	0	0	0	22
.056	215	44.6	127.4	13.6	98.4	S. 45° 41′ E.	118.5	0	0	0	23
.051	230	140.9	63.9	17.2	66.9	N. 32° 51′ E.	91.6	0	0	0	24
.204	288	62.0	160.4	0	150.3	S. 56° 48′ E.	179.6	0	0	0	25
.210	190	131.3	29.6	3.2	61.8	N. 29° 57′ E.	117.4	2 p.m.	3 p.m.	02	26
.160	111	33.3	57.1	13.1	35.0	S. 42° 37′ E.	32.3	0	0	0	27
.076	164	60.9	91.7	12.4	31.5	S. 31° 48′ E.	36.2	0	0	0	28
.022	200	137.1	44.7	10.7	47.4	N. 21° 40′ E.	99.4	0	0	0	29
.097	142	69.3	50.6	10.3	50.2	N. 64° 53′ E.	44.0	3 p.m.	8 p.m.	20	30
.717	6098	2278.1	2694.3	772.5	1851.3	.....	.....	.....	.....	0.40	....
.024	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	....
.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	....

MONTHLY SUMMARY OF

JULY,

DATE.	THERMOMETERS.					PSYCHROMETER.						SUNSHINE RECO		
	TEMPERATURES.			Hours of Extremes.		Relative Humidity.			Dew-point.			Clouds at Observations	Number Minutes	
	Mean of 24 hrs.	Extremes.				6 A.M.	12 M.	6 P.M.	6 A.M.	12 M.	6 P.M.		Actual.	Possible
		Max.	Min.	Max.	Min.									
1	63.4	79	50	2 p.m.	5 a.m.	68	28	45	46	41	45	17	370	862
2	66.5	80	52	12 m.	5 a.m.	63	35	28	42	49	39	9	655	862
3	67.2	83	50	12 m.	5 a.m.	47	26	25	39	43	39	10	580	862
4	71.9	88	54	1 p.m.	5 a.m.	51	18	30	45	39	42	7	470	860
5	72.7	83	59	12 m.	12 n't	24	24	24	32	42	40	9	340	860
6	67.7	83	51	2 p.m.	5 a.m.	48	36	33	45	50	41	10	421	860
7	67.0	82	51	1 p.m.	4 a.m.	53	34	40	49	47	47	14	410	860
8	69.2	82	55	4 p.m.	2 a.m.	59	34	31	49	50	41	13	350	859
9	65.8	81	53	1 p.m.	5 a.m.	52	32	41	42	47	46	13	425	859
10	66.7	78	55	1 p.m.	4 a.m.	57	28	37	52	41	46	9	440	857
11	64.8	76	55	1 p.m.	5 a.m.	69	55	55	48	53	53	12	615	857
12	67.3	82	56	1 p.m.	5 a.m.	61	30	33	54	46	42	12	585	856
13	66.2	80	55	2 p.m.	5 a.m.	62	43	53	49	46	67	14	330	856
14	60.7	73	53	4 p.m.	5 a.m.	73	54	39	46	45	45	18	245	854
15	66.7	83	48	3 p.m.	5 a.m.	67	25	12	43	39	23	0	550	852
16	64.6	73	53	4 p.m.	5 a.m.	63	24	32	42	32	39	2	720	850
17	68.1	82	58	2 p.m.	6 a.m.	61	28	33	55	45	42	2	550	849
18	70.9	88	50	4 p.m.	6 a.m.	66	15	20	40	30	33	7	510	847
19	72.3	85	61	2 p.m.	6 a.m.	42	17	26	40	34	43	5	540	846
20	71.1	88	57	2 p.m.	5 a.m.	55	24	34	42	44	47	11	475	844
21	70.3	85	57	3 p.m.	2 a.m.	44	20	40	38	36	47	19	405	843
22	67.5	80	56	3 p.m.	4 a.m.	52	47	33	42	54	42	14	420	841
23	71.3	90	53	3 p.m.	5 a.m.	49	28	18	37	45	36	8	570	839
24	73.1	88	59	3 p.m.	3 a.m.	36	26	32	38	43	45	12	455	837
25	64.5	80	59	10 a.m.	5 a.m.	48	88	85	40	54	57	21	130	837
26	58.5	64	57	3 p.m.	12 n't	89	95	95	55	57	58	30	0	836
27	62.1	74	57	1 p.m.	5 a.m.	95	53	80	58	56	56	29	175	835
28	62.2	73	54	10 a.m.	12 n't	84	68	88	54	55	55	22	305	833
29	62.7	78	52	4 p.m.	5 a.m.	83	53	57	50	56	62	11	580	831
30	67.6	81	55	3 p.m.	3 a.m.	75	34	34	52	47	46	15	365	829
31	62.2	69	57	1 p.m.	5 a.m.	55	61	73	41	55	57	19	355	827
Sums,	2072.8	2491	1692	.....	.....	1851	1183	1346	1405	1421	1421	394	....	....
Means,	66.9	80.4	54.6	.....	.....	60	38	43	45	46	46	13	....	....
Perc'g,	.....	.....	.....	.....	.....	....	....	....	....	....	....	42%	....	....

INSTRUMENTAL RECORD.

1907.

BAROMETER.	ANEMOMETER AND ANEMOSCOPE.							RAIN GAUGE.			Date.
	WIND.							Hours of Fall.		Total Amount.	
Actual Pressure 12 M.	Total Velocity.	Sum of Components. N.	S.	W.	E.	Equivalent. Direction.	Miles.	Earliest.	Latest.		
.209	148	73.8	45.5	38.7	25.4	N. 25° 10′ W.	31.2	3 p.m.	4 p.m.	10	1
.244	172	42.8	105.1	13.3	53.6	S. 32° 54′ E.	74.2	0	0	0	2
.219	162	59.7	67.1	20.3	64.6	S. 80° 31′ E.	44.9	.....	.....	T	3
.163	131	82.0	24.3	18.7	33.6	N. 14° 29′ E.	59.6	0	0	0	4
.213	243	196.0	5.4	65.6	15.2	N. 14° 49′ W.	197.2	0	0	0	5
.107	163	32.2	93.2	4.2	89.9	S. 54° 34′ E.	105.2	.....	.....	T	6
.095	231	225.1	0	44.9	20.2	N. 6° 16′ W.	226.5	0	0	0	7
.065	223	87.7	50.3	113.2	38.3	N. 63° 28′ W.	83.7	.....	.....	T	8
.085	216	133.9	27.1	82.7	27.6	N. 27° 18′ W.	120.2	3 p.m.	4 p.m.	.09	9
.109	164	157.7	16.2	17.3	17.7	N. 0° 10′ E.	141.5	0	0	0	10
.201	158	30.8	89.5	0.6	81.0	S. 53° 52′ E.	99.6	2 a.m.	3 p.m.	.10	11
.119	140	62.0	44.4	24.2	37.3	N. 36° 40′ E.	21.9	0	0	0	12
.007	206	158.1	9.3	87.5	6.8	N. 28° 28′ W.	169.3	8 p.m.	9 p.m.	T	13
.884	136	98.2	20.5	26.2	19.3	N. 5° 04′ W.	78.0	1 a.m.	2 a.m.	20	14
.877	162	68.8	54.4	47.4	16.9	N. 64° 44′ W.	33.7	0	0	0	15
.180	305	91.6	117.9	42.2	94.1	S. 63° 08′ E.	58.2	0	0	0	16
.147	184	4.7	133.0	1.6	107.9	S. 39° 38′ E.	166.6	0	0	0	17
.119	161	72.2	19.5	26.7	14.9	N. 12° 37′ W.	54.0	0	0	0	18
.173	214	130.3	39.2	12.9	70.8	N. 32° 26′ E.	108.0	0	0	0	19
.070	195	157.6	14.7	13.2	41.3	N. 11° 08′ E.	145.6	2 p.m.	4 p.m.	T	20
.138	166	116.0	21.9	42.6	20.2	N. 13° 23′ W.	96.7	0	0	0	21
.223	[292]	27.0	31.8	8.8	29.2	S. 76° 46′ E.	21.0	0	0	0	22
.141	[ ]	26.0	14.5	10.7	39.0	N. 67° 53′ E.	30.6	0	0	0	23
.084	151	108.8	25.3	35.4	21.0	N. 9° 47′ W.	84.7	0	0	0	24
.121	154	121.1	14.9	34.5	19.2	N. 8° 12′ W.	107.3	12 m.	12 n't	38	25
.156	137	42.3	63.8	12.7	62.7	S. 66° 44′ E.	54.4	1 a.m.	12 n't	60	26
.054	134	95.6	11.2	52.2	18.5	N. 21° 46′ W.	90.9	7 p.m.	.....	51	27
.216	123	61.2	41.0	11.1	32.8	N. 46° 03′ E.	29.6	6 p.m.	9 p.m.	.06	28
.242	106	39.5	32.0	19.1	39.8	N. 70° 05′ E.	22.0	0	0	0	29
.302	173	104.0	48.2	44.1	5.1	N. 34° 57′ W.	68.1	.....	.....	T	30
.302	174	88.9	55.3	11.4	59.0	N. 54° 47′ E.	58.3	4 p.m.	6 p.m.	.07	31
.265	5324	2795.6	1336.5	984.0	1222.9	.....	.....	.....	.....	2.11	....
.138	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	....
...	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	....

MONTHLY SUMMARY OF

AUGUST,

DATE.	THERMOMETERS.					PSYCHROMETER.						SUNSHINE REC		
	TEMPERATURES.			Hours of Extremes.		Relative Humidity.			Dew-point.			Clouds at Observations	Number Minute	
	Mean of 24 hrs.	Extremes.				6 A.M.	12 M.	6 P.M.	6 A.M.	12 M.	6 P.M.		Actual.	Possible
		Max.	Min.	Max.	Min.									
1	62.5	76	52	2 p.m.	5 a.m.	73	55	95	46	53	57	25	295	824
2	61.9	74	53	2 p.m.	5 a.m.	89	56	68	52	55	54	18	200	821
3	62.2	72	56	3 p.m.	2 a.m.	80	55	68	53	54	54	20	215	818
4	69.0	83	56	3 p.m.	2 a.m.	68	20	36	53	35	47	8	420	816
5	69.0	82	52	3 p.m.	5 a.m.	45	15	29	35	30	41	0	310	814
6	72.5	86	56	2 p.m.	1 a.m.	42	22	31	40	39	44	10	425	812
7	68.7	83	56	2 p.m.	12 n't	52	28	47	47	44	52	7	135	809
8	71.5	86	54	3 p.m.	3 a.m.	51	17	25	34	34	39	5	655	807
9	72.0	87	58	1 p.m.	1 a.m.	50	27	31	48	46	44	13	350	805
10	73.5	87	57	1 p.m.	2 a.m.	52	18	27	47	36	42	6	515	803
11	62.6	79	50	3 p.m.	5 a.m.	55	31	36	41	38	40	3	575	800
12	64.0	78	44	2 p.m.	5 a.m.	54	40	51	39	48	51	14	245	798
13	65.6	82	55	3 p.m.	12 n't	46	23	56	37	38	49	7	195	796
14	68.2	84	50	12 m.	3 a.m.	57	24	44	44	42	48	8	350	794
15	73.1	84	61	2 p.m.	12 n't	54	17	17	52	33	33	10	695	792
16	68.7	86	54	2 p.m.	6 a.m.	69	20	24	48	38	38	10	545	790
17	69.0	86	52	2 p.m.	5 a.m.	59	15	35	40	31	45	3	475	787
18	67.3	86	55	2 p.m.	5 a.m.	52	21	54	47	40	52	12	185	784
19	59.6	71	53	1 p.m.	6 a.m.	78	68	75	47	54	52	21	240	780
20	54.4	63	48	6 p.m.	4 a.m.	83	88	80	47	49	43	27	20	777
21	58.0	72	49	2 p.m.	4 a.m.	78	61	78	47	43	49	22	180	773
22	65.2	80	53	3 p.m.	5 a.m.	83	23	35	50	36	45	11	506	772
23	67.5	86	51	3 p.m.	4 a.m.	73	20	22	46	35	37	4	720	770
24	66.2	86	51	3 p.m.	5 a.m.	73	19	34	46	34	44	15	330	769
25	66.4	85	51	12 m.	5 a.m.	78	23	57	42	42	51	13	....	767
26	66.0	79	49	2 p.m.	5 a.m.	58	26	48	42	40	50	15	....	764
27	60.5	75	50	3 p.m.	5 a.m.	77	51	52	46	57	47	20	....	760
28	63.6	81	50	2 p.m.	3 a.m.	77	24	38	45	38	44	11	....	758
29	59.1	72	49	1 p.m.	2 a.m.	64	34	85	45	52	55	12	....	755
30	62.7	76	55	11 a.m.	5 a.m.	84	26	36	51	36	16	20	....	752
31	61.1	70	52	1 p.m.	4 a.m.	57	38	48	44	41	46	29	....	750
Sums,	2031.6	2477	1632	.....	.....	2011	1005	1462	1401	1291	1409	399	....	....
Means,	65.5	79.9	52.6	.....	.....	65	32	47	45	42	45	13	....	....
Perc'g,	.....	.....	.....	.....	.....	....	....	....	....	....	....	43%	....	....

INSTRUMENTAL RECORD.

1907.

...ROM-ETER. ...ual ...sure ...2 M.	ANEMOMETER AND ANEMOSCOPE. WIND. Total Velocity.	Sum of Components. N.	S.	W.	E.	Equivalent. Direction.	Miles.	RAIN GAUGE. Hours of Fall. Earliest.	Latest.	Total Amount.	Date.
199	137	81.0	16.3	56.7	23.5	N. 27° 10′ W.	72.7	.....	.....	1.17	1
156	112	44.3	48.1	6.1	43.1	S. 84° 08′ E.	37.2	7 p.m.	9 p.m.	.06	2
122	149	30.2	69.2	0	101.4	S. 68° 58′ E.	108.6	0	0	0	3
025	210	162.2	0	100.3	7.3	N. 29° 50′ W.	187.0	.....	.....	T	4
139	145	93.8	23.0	38.8	26.5	N. 7° 52′ W.	71.5	0	0	0	5
225	161	123.9	3.7	62.4	21.4	N. 18° 50′ W.	127.0	0	0	0	6
227	148	115.5	3.8	35.9	29.3	N. 3° 23′ W.	111.9	.....	.....	T	7
261	146	80.0	41.1	9.4	48.3	N. 45° 00′ E.	55.0	0	0	0	8
136	146	100.1	18.6	44.3	23.0	N. 14° 39′ W.	84.3	0	0	0	9
047	186	64.9	61.6	97.4	10.0	N. 87° 50′ W.	87.5	0	0	0	10
195	298	106.4	125.2	24.6	136.0	S. 80° 25′ E.	113.0	0	0	0	11
156	142	37.7	49.8	72.3	19.9	S. 77° 00′ W.	53.8	.....	.....	T	12
235	123	94.4	3.7	42.6	15.3	N. 16° 45′ W.	94.7	.....	.....	07	13
183	148	105.8	16.0	26.8	26.4	N. 0° 15′ W.	89.8	0	0	0	14
115	235	106.7	15.0	120.6	19.4	N. 34° 47′ W.	177.4	0	0	0	15
143	138	72.1	42.7	0	47.6	N. 58° 18′ E.	56.0	0	0	0	16
183	140	108.6	13.6	10.7	27.1	N. 9° 48′ E.	96.4	.....	.....	T	17
086	[647]	66.3	2.5	11.2	18.2	N. 6° 16′ E.	64.2	.....	.....	T	18
286	[ ]	30.2	24.6	1.2	34.0	N. 80° 19′ E.	33.3	.....	.....	05	19
265	[ ]	0	54.0	0	56.0	S. 46° 03′ E.	77.8	.....	.....	T	20
217	[ ]	20.4	54.3	13.6	48.0	S. 45° 25′ E.	48.3	4 p.m.	6 p.m.	46	21
132	108	66.6	12.2	43.4	14.1	N. 28° 19′ W.	61.8	0	0	0	22
220	128	116.3	0	10.3	20.5	N. 5° 01′ E.	116.8	0	0	0	23
195	188	97.0	73.2	18.8	30.9	N. 27° 15′ E.	26.4	0	0	0	24
003	145	96.7	3.4	51.6	15.6	N. 21° 06′ W.	100.0	.....	.....	T	25
012	125	28.2	70.9	7.6	54.8	S. 47° 52′ E.	63.6	0	0	0	26
080	118	64.3	40.0	2.0	35.8	N. 54° 17′ E.	41.6	.....	.....	T	27
076	138	70.5	44.6	30.1	19.0	N. 23° 12′ W.	28.2	0	0	0	28
078	129	67.8	31.8	39.8	22.7	N. 25° 25′ W.	39.9	3 p.m.	6 p.m.	10	29
956	160	10.3	116.0	4.0	61.9	S. 28° 43′ E.	120.5	.....	.....	T	30
235	196	176.0	0	59.9	7.3	N. 16° 38′ W.	183.7	0	0	0	31
588	4846	2438.2	1078.9	1042.4	1064.3	.....	.....	.....	.....	1.91	....
148	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	....
....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	....

MONTHLY SUMMARY OF

SEPTEMBER,

DATE.	THERMOMETERS.					PSYCHROMETER.						SUNSHINE R	
	TEMPERATURES.			Hours of Extremes.		Relative Humidity.			Dew-point.			Clouds at Observations	Number Minut
	Mean of 24 hrs.	Extremes. Max.	Extremes. Min.	Max.	Min.	6 A.M.	12 M.	6 P.M.	6 A.M.	12 M.	6 P.M.		Actual.	Possible
1	60.5	73	51	12 m.	5 a.m.	76	41	57	44	46	52	12	317	745
2	64.1	79	47	1 p.m.	5 a.m.	71	36	28	42	43	39	5	599	742
3	65.3	81	50	3 p.m.	5 a.m.	77	20	31	45	35	41	4	594	739
4	63.2	76	49	2 p.m.	6 a.m.	70	34	49	41	44	47	16	501	737
5	63.5	81	55	3 p.m.	6 a.m.	95	65	42	53	56	47	10	280	734
6	66.7	81	51	2 p.m.	6 a.m.	53	19	23	38	31	35	(?)8	526	732
7	61.0	74	53	11 a.m.	5 a.m.	68	33	54	44	41	45	15	366	729
8	53.5	69	44	3 p.m.	6 a.m.	68	58	54	34	48	45	18	195	725
9	51.6	62	43	4 p.m.	3 a.m.	86	36	40	40	33	32	8	585	722
10	56.1	75	33	4 p.m.	6 a.m.	91	10	26	32	14	31	0	684	720
11	64.5	78	48	3 p.m.	2 a.m.	46	17	19	32	27	26	2	660	715
12	67.5	83	48	3 p.m.	3 a.m.	36	12	18	29	25	29	10	540	711
13	66.2	78	54	4 p.m.	6 a.m.	37	22	23	31	34	33	16	95	706
14	62.6	78	51	2 p.m.	12 n't	37	23	67	36	35	51	21	98	704
15	63.3	80	45	3 p.m.	3 a.m.	64	23	23	37	36	33	7	561	702
16	66.5	80	50	4 p.m.	6 a.m.	51	17	33	34	30	42	2	586	700
17	68.3	82	53	3 p.m.	12 n't	52	17	25	37	30	34	4	471	697
18	65.0	79	50	2 p.m.	5 a.m.	56	15	40	37	27	43	13	440	696
19	64.6	77	48	3 p.m.	12 n't	44	24	41	37	37	45	0	635	694
20	50.3	60	36	3 p.m.	6 a.m.	70	26	40	29	25	32	3	612	693
21	53.5	67	36	3 p.m.	5 a.m.	70	25	52	30	28	42	0	570	690
22	57.3	76	37	4 p.m.	6 a.m.	85	8	15	35	12	19	10	507	689
23	60.6	78	40	3 p.m.	6 a.m.	35	12	41	19	20	45	0	613	687
24	57.3	66	48	3 p.m.	12 n't	44	35	41	29	36	37	6	563	685
25	58.5	78	42	3 p.m.	5 a.m.	68	29	41	34	34	45	17	43	681
26	59.5	75	48	3 p.m.	4 a.m.	60	24	68	44	36	46	18	367	679
27	53.7	67	40	2 p.m.	6 a.m.	86	26	60	36	29	44	1	546	675
28	54.5	70	36	3 p.m.	4 a.m.	92	37	63	35	39	51	2	511	671
29	49.2	57	38	1 p.m.	12 n't	85	59	86	39	43	39	14	536	668
30	43.8	56	33	5 p.m.	5 a.m.	84	80	44	32	39	29	19	152	666
Sums,	1792.2	2216	1357	.....	.....	1957	883	1244	1085	1013	1179	261	...	...
Means,	59.7	73.9	45.2	.....	.....	65	29	41	36	34	39	9	...	...
Perc'g,	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	29%	.....	.....

INSTRUMENTAL RECORD.

1907.

Baro-meter.	Anemometer and Anemoscope. WIND. Total Velocity.	Sum of Components. N.	S.	W.	E.	Equivalent. Direction.	Miles.	Rain Gauge. Hours of Fall. Earliest.	Latest.	Total Amount.	Date.
776	113	60.3	22.2	43.6	8.8	N. 42° 25′ W.	51.6	.. a.m.	4 p.m.	T	1
742	113	59.1	39.6	4.9	30.8	N. 54° 28′ E.	31.8	0	0	0	2
744	135	108.5	9.6	2.2	28.9	N. 15° 53′ E.	102.4	0	0	0	3
726	199	85.8	86.5	2.8	73.8	S. 89° 26′ E.	71.0	.....	.....	04	4
734	118	62.6	36.5	0.4	42.6	N. 58° 16′ E.	49.6	0	0	0	5
726	137	94.0	19.9	26.5	29.0	N. 1° 56′ E.	74.1	0	0	0	6
704	[512]	105.0	0	17.5	3.9	N. 7° 23′ W.	105.9	.....	.....	01	7
746	.....	.....	.....	.....	.....	.....	.....	0	0	0	8
755	[ ]	113.8	3.6	0	37.2	N. 18° 39′ E.	116.3	.....	.. a.m.	.33	9
786	130	66.3	49.5	7.9	36.4	N. 59° 29′ E.	33.1	0	0	0	10
776	160	82.6	54.8	3.3	53.6	N. 54° 50′ E.	61.5	0	0	0	11
786	168	94.3	40.9	60.2	6.7	N. 45° 04′ W.	75.6	0	0	0	12
783	155	66.4	43.7	82.8	10.5	N. 72° 34′ W.	75.8	0	0	0	13
765	119	62.3	16.0	39.9	40.2	N. 0° 22′ E.	46.3	3 p.m.	4 p.m.	T	14
788	78	34.9	20.4	20.8	19.3	N. 5° 54′ W.	14.6	0	0	0	15
726	101	33.2	49.6	34.3	14.3	S. 50° 39′ W.	25.9	0	0	0	16
747	152	69.9	27.5	66.6	26.8	N. 43° 11′ W.	58.2	0	0	0	17
705	164	43.2	84.5	56.2	16.6	S. 43° 48′ W.	57.2	0	0	0	18
702	208	83.4	34.3	109.4	34.0	N. 56° 56′ W.	90.0	0	0	0	19
793	215	29.5	134.1	5.9	126.0	S. 48° 57′ E.	159.3	0	0	0	20
744	220	174.6	21.2	12.0	52.7	N. 14° 52′ E.	158.7	0	0	0	21
799	135	92.4	17.9	32.7	22.7	N. 7° 39′ W.	75.2	0	0	0	22
725	157	91.9	46.6	17.2	39.9	N. 26° 37′ E.	50.7	0	0	0	23
797	283	91.1	128.8	4.9	143.7	S. 74° 48′ E.	143.8	0	0	0	24
737	126	83.0	12.7	50.5	0.5	N. 35° 25′ W.	86.3	0	0	0	25
790	271	179.1	66.8	27.4	63.2	N. 17° 41′ E.	117.9	0	0	0	26
751	158	44.0	76.9	18.8	68.7	S. 56° 36′ E.	59.8	.....	.....	T	27
767	156	39.0	96.2	6.9	51.0	S. 38° 37′ E.	70.6	0	0	0	28
711	328	323.3	0	11.5	29.4	N. 3° 10′ E.	323.8	0	0	0	29
735	151	79.6	51.4	19.8	30.0	N. 19° 53′ E.	30.0	.....	.. a.m.	30	30
116	4962	2553.2	1291.7	786.9	1141.2	.....	.....	.....	.....	0.68	....
94	.....	.....	.....	.....	.....	.....	.....	.....	.....	....	....
....	.....	....	.....	.....	.....	.....	.....	.....	.....	....	....

MONTHLY SUMMARY OF

OCTOBER,

DATE.	THERMOMETERS.					PSYCHROMETER.						SUNSHINE R	
	TEMPERATURES.			Hours of Extremes.		Relative Humidity.			Dew-point.			Clouds at Observations	Numl Minu
	Mean of 24 hrs.	Extremes.				6 A.M.	12 M.	6 P.M.	6 A.M.	12 M.	6 P.M.		Act-ual.	Pc sib
		Max.	Min.	Max.	Min.									
1	54.5	71	43	4 p.m.	1 a.m.	31	21	48	23	24	40	4	310	66
2	53.5	68	39	3 p.m.	7 a.m.	52	14	56	26	17	43	17	255	66
3	43.9	52	36	2 p.m.	12 n't	66	58	63	32	34	35	20	210	66
4	49.6	66	34	4 p.m.	6 a.m.	100	21	63	35	24	42	0	495	65
5	52.2	70	33	4 p.m.	6 a.m.	75	25	46	29	30	42	0	500	65
6	61.0	75	43	12 m.	3 a.m.	38	18	55	32	29	47	8	402	65
7	48.2	60	42	4 p.m.	7 a.m.	46	61	61	24	39	39	8	443	65
8	52.2	70	35	3 p.m.	6 a.m.	84	21	25	32	27	25	0	544	64
9	48.8	61	39	4 p.m.	6 a.m.	71	39	38	31	31	29	6	546	64
10	55.5	73	37	2 p.m.	1 a.m.	53	17	27	28	24	27	1	580	64
11	50.2	62	37	2 p.m.	6 a.m.	60	28	42	26	27	30	5	506	63
12	50.2	65	36	2 p.m.	4 a.m.	70	29	40	30	32	32	8	367	63
13	54.0	71	37	2 p.m.	6 a.m.	84	23	55	33	28	47	4	472	63
14	56.0	70	47	1 p.m.	5 a.m.	46	28	64	32	33	45	9	337	63
15	49.6	61	37	2 p.m.	6 a.m.	92	48	48	37	40	36	7	476	63
16	49.5	66	34	2 p.m.	6 a.m.	84	35	35	32	36	31	0	562	63
17	52.0	66	37	10 a.m.	3 a.m.	49	22	44	28	24	34	9	544	63
18	44.8	57	34	2 p.m.	6 a.m.	92	56	59	33	37	36	10	392	63
19	50.5	65	32	2 p.m.	3 a.m.	84	21	44	32	24	29	0	492	6
20	45.0	56	36	1 p.m.	7 a.m.	75	36	45	29	26	26	7	493	6
21	47.6	65	28	2 p.m.	6 a.m.	80	18	28	25	21	25	3	486	6
22	51.7	65	37	11 a.m.	7 a.m.	62	29	56	26	29	43	13	404	6
23	51.1	66	34	3 p.m.	5 a.m.	68	26	34	27	29	30	4	367	6
24	45.5	51	42	5 a.m.	10 p.m.	87	64	86	44	37	39	30	0	6
25	45.2	55	41	11 a.m.	12 n't	79	56	80	37	38	40	25	155	6
26	47.8	60	34	2 p.m.	6 a.m.	76	30	54	30	28	34	0	534	5
27	40.4	46	35	2 p.m.	12 n't	75	67	50	29	33	24	14	372	5
28	50.3	69	33	1 p.m.	1 a.m.	77	28	42	33	33	35	10	272	5
29	48.0	60	34	3 p.m.	12 n't	78	29	50	36	27	33	2	525	5
30	45.9	61	29	3 p.m.	5 a.m.	91	29	56	30	27	37	7	487	5
31	49.6	60	40	2 p.m.	9 p.m.	28	28	80	22	25	39	15	237	5
Sums,	1544.3	1963	1135	.....	.....	2153	1025	1574	943	913	1094	246	.....	.
Means,	49.8	63.3	36.6	.....	.....	69	33	51	30	29	35	8	.....	.
Perc'g,	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	26%	.....	.

INSTRUMENTAL RECORD.

1907.

ROM-ER.	ANEMOMETER AND ANEMOSCOPE.							RAIN GAUGE.			
	WIND.							Hours of Fall.		Total Amount.	Date.
tual sure 12 M.	Total Velocity.	Sum of Components.				Equivalent.		Earliest.	Latest.		
		N.	S.	W.	E.	Direction.	Miles.				
.940	126	53.0	37.2	17.9	44.7	N. 59° 28′ E.	31.1	0	0	0	1
.861	238	189.8	23.2	33.2	43.3	N. 3° 28′ E.	166.9	0	0	0	2
.232	315	261.8	29.5	20.9	67.6	N. 11° 22′ E.	236.9	0	0	0	3
.273	182	169.1	1.1	6.6	42.5	N. 12° 04′ E.	171.8	0	0	0	4
.133	139	80.4	39.5	0.5	43.1	N. 46° 10′ E.	59.1	0	0	0	5
.906	289	251.5	0	45.8	49.3	N. 0° 48′ E.	251.5	0	0	0	6
.247	338	262.4	24.3	180.1	25.9	N. 32° 56′ W.	283.3	.....	.. a.m.	.05	7
.201	159	146.3	0	2.5	37.2	N. 13° 21′ E.	150.4	0	0	0	8
.387	154	60.1	66.8	3.6	66.6	S. 83° 56′ E.	63.3	0	0	0	9
.271	143	97.3	40.1	3.5	13.7	N. 10° 02′ E.	58.6	0	0	0	10
.268	182	74.6	75.7	6.7	74.4	S. 89° 04′ E.	67.7	0	0	0	11
.195	111	49.8	47.0	1.8	37.5	N. 85° 31′ E.	35.8	0	0	0	12
.076	145	89.3	30.4	28.8	27.2	N. 1° 33′ W.	58.9	0	0	0	13
.160	116	53.0	46.1	19.2	29.4	N. 55° 56′ E.	12.3	3 p.m.	4 p.m.	.01	14
.232	108	40.7	46.5	0	50.2	S. 83° 25′ E.	50.5	.....	.. a.m.	.02	15
.199	129	76.7	39.6	0.5	32.3	N. 40° 36′ E.	48.8	0	0	0	16
.299	238	229.8	0	22.0	15.3	N. 1° 40′ W.	229.9	0	0	0	17
.261	150	19.9	92.9	1.3	89.9	S. 50° 31′ E.	114.8	.....	.. a.m.	T	18
.099	215	209.2	0	8.9	24.8	N. 4° 21′ E.	209.7	0	0	0	19
.246	189	64.9	89.3	5.1	80.2	S. 72° 00′ E.	79.0	0	0	0	20
.167	144	130.3	4.1	3.1	29.8	N. 11° 57′ E.	129.0	0	0	0	21
.192	148	74.3	59.1	18.4	21.8	N. 12° 37′ E.	15.6	0	0	0	22
.115	144	75.6	50.5	0	37.6	N. 56° 16′ E.	45.2	0	0	0	23
.150	174	124.7	11.7	93.8	5.5	N. 38° 00′ W.	143.4	6 a.m.	.....	.39	24
.156	164	62.2	74.4	20.8	56.7	S. 71° 14′ E.	37.9	.....	.. a.m.	.22	25
.122	127	55.0	49.2	1.1	54.5	N. 83° 48′ E.	53.7	0	0	0	26
.247	206	28.8	126.2	2.5	121.0	S. 50° 35′ E.	153.4	0	0	0	27
.838	169	115.7	19.9	43.6	23.7	N. 11° 44′ W.	97.9	0	0	0	28
.010	139	88.3	41.4	10.7	23.9	N. 15° 43′ E.	48.7	0	0	0	29
.055	148	78.2	46.5	1.3	52.5	N. 58° 14′ E.	60.2	0	0	0	30
.974	152	77.5	40.8	43.5	30.6	N. 19° 22′ W.	38.9	.....	.....	T	31
.512	5381	3390.2	1253.0	647.7	1352.8	.....	.....	.....	.....	0.69	....
.146	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	....
....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	....

MONTHLY SUMMARY OF

NOVEMBER,

DATE.	THERMOMETERS.					PSYCHROMETER.						SUNSHINE REC		
	TEMPERATURES.			Hours of Extremes.		Relative Humidity.			Dew-point.			Clouds at Observations	Number Minutes	
	Mean of 24 hrs.	Extremes.				6 A.M.	12 M.	6 P.M.	6 A.M.	12 M.	6 P.M.		Actual.	Possible
		Max.	Min.	Max.	Min.									
1	43.9	55	31	2 p.m.	12 n't	82	29	40	30	23	25	0	529	586
2	45.3	65	28	2 p.m.	7 a.m.	90	19	44	28	20	29	0	540	582
3	46.3	60	32	2 p.m.	6 a.m.	57	18	28	27	16	20	0	524	579
4	45.6	58	34	3 p.m.	7 a.m.	47	26	37	21	22	32	0	474	578
5	44.0	57	29	2 p.m.	6 a.m.	39	19	37	13	16	20	0	575	576
6	49.1	65	32	1 p.m.	1 a.m.	33	12	16	20	14	11	16	141	574
7	48.4	59	40	3 a.m.	12 n't	38	29	35	26	23	22	10	344	572
8	41.7	56	30	2 p.m.	6 a.m.	81	31	34	25	23	17	4	476	570
9	41.8	57	28	1 p.m.	12 n't	41	27	38	22	23	22	0	484	568
10	22.8	32	11	4 a.m.	12 n't	39	75	87	22	16	17	29	0	566
11	17.1	26	6	2 p.m.	7 a.m.	76	12	87	9	12	17	2	405	565
12	23.4	39	7	3 p.m.	7 a.m.	92	27	70	6	7	21	0	484	563
13	33.4	49	20	2 p.m.	7 a.m.	43	28	37	6	16	14	0	497	561
14	30.1	50	11	1 p.m.	6 a.m.	93	27	49	9	18	19	2	476	559
15	33.9	44	24	2 p.m.	7 a.m.	32	29	52	0	14	21	3	346	558
16	31.5	43	20	3 p.m.	6 a.m.	87	58	75	17	28	28	0	432	556
17	37.0	53	22	11 a.m.	2 a.m.	54	33	36	11	20	17	10	411	554
18	28.3	38	19	1 a.m.	12 n't	68	79	89	19	24	23	27	0	552
19	24.5	36	12	3 p.m.	5 a.m.	100	90	78	16	29	21	17	40	551
20	32.0	43	19	1 p.m.	1 a.m.	66	32	100	25	15	31	22	53	549
21	28.4	37	22	3 p.m.	8 a.m.	77	48	61	19	17	20	8	397	548
22	27.6	43	13	3 p.m.	6 a.m.	71	28	46	10	11	15	0	471	547
23	35.9	52	18	1 p.m.	3 a.m.	59	13	44	17	5	21	3	430	545
24	36.9	53	18	3 p.m.	7 a.m.	88	16	30	19	7	13	6	437	543
25	43.4	60	27	2 p.m.	12 n't	33	12	21	10	7	12	10	375	541
26	44.4	63	22	3 p.m.	6 a.m.	38	17	33	9	14	23	5	490	540
27	37.1	52	23	1 a.m.	12 n't	90	26	43	28	14	16	0	442	539
28	33.1	49	19	2 p.m.	4 a.m.	88	24	46	19	14	19	12	24	538
29	36.4	57	19	2 p.m.	6 a.m.	87	18	23	17	16	10	2	402	537
30	35.9	52	24	1 p.m.	6 a.m.	75	17	44	17	11	18	1	386	536
Sums,	1079.2	1503	660	.....	.....	1964	919	1460	517	495	594	189	....	....
Means,	36.0	50.1	22.0	.....	.....	65	31	49	17	16	20	6	....	....
Perc'g,	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	21%	....	....

INSTRUMENTAL RECORD.

1907.

...ome-ter.	Anemometer and Anemoscope.							Rain Gauge.			Date.
	Wind.							Hours of Fall.		Total Amount.	
...tual ...sure 12 M.	Total Velocity.	Sum of Components. N.	S.	W.	E.	Equivalent. Direction.	Miles.	Earliest.	Latest.		
.193	148	78.4	45.0	73.3	57.5	N. 56° 22′ E.	60.3	0	0	0	1
.036	146	83.8	46.1	4.6	37.8	N. 41° 22′ E.	50.2	0	0	0	2
.068	166	95.3	49.7	7.1	49.3	N. 42° 47′ E.	62.1	0	0	0	3
.170	213	113.6	60.4	24.1	70 5	N. 41° 06′ E.	70.6	0	0	0	4
.255	192	88.5	75.9	6.3	65.6	N. 78° 00′ E.	60.6	0	0	0	5
.990	116	79.6	30.4	9.6	13.1	N. 4° 04′ E.	49.3	0	0	0	6
.048	218	199.1	3.2	20.7	30.0	N. 3° 55′ E.	136.2	0	0	0	7
.130	106	45.4	48.8	1.1	52.3	S. 86° 12′ E.	51.3	0	0	0	8
.199	142	81.6	40.8	4.8	39.6	N. 59° 08′ E.	40.5	0	0	0	9
.205	150	51.5	31.2	7.0	47.8	N. 63° 33′ E.	45.6	7 a.m.	.....	28	10
265	92	47.6	13.1	1.7	52.4	N. 55° 46′ E.	61.3	0	0	0	11
.208	128	107.1	22.5	1.6	23.1	N. 14° 15′ E.	87.3	0	0	0	12
.104	180	90.0	67.4	1.2	59.9	N. 68° 56′ E.	62.9	0	0	0	13
.034	113	68.3	33.2	0.1	29.5	N. 39° 57′ E.	45.8	0	0	0	14
.144	234	69.8	114.7	0.5	117.4	S. 69° 00′ E.	125.2	0	0	0	15
.130	90	50.5	25.5	0	27.4	N. 47° 38′ E.	37.1	0	0	0	16
.904	133	92.6	0	0.1	54.5	N. 30° 26′ E.	107.4	0	0	0	17
.941	317	311.2	0	23.9	17.2	N. 1° 14′ W.	311.2	6 a.m.	4 p.m.	.01	18
.954	110	54.5	39.1	5.2	37.1	N. 64° 14′ E.	35.4	0	0	0	19
.777	142	50.1	44.1	42.3	37.4	N. 39° 14′ W.	7.7	6 p.m.	.....	T	20
.005	88	35.5	31.8	21.1	28.8	N. 64° 20′ E.	8.5	.....	.. a.m.	T	21
.065	135	96.3	28.1	4.3	25.8	N. 17° 30′ E.	71.5	0	0	0	22
.017	118	86.7	21.0	22.0	6.0	N. 13° 41′ W.	67.6	0	0	0	23
.107	159	117.1	19.1	41.1	17.8	N. 13° 22′ W.	100.7	0	0	0	24
.244	118	85.8	16.9	13.3	27.7	N. 11° 48′ E.	70.4	0	0	0	25
.011	149	89.9	11.5	68.7	7.3	N. 38° 04′ W.	99.6	0	0	0	26
.108	172	68.1	65.4	14.8	74.2	N. 87° 24′ E.	59.5	0	0	0	27
.170	183	181.3	0	2.8	11.4	N. 2° 43′ E.	181.5	0	0	0	28
.249	142	96.5	11.9	3.0	14.5	N. 7° 44′ E.	85.4	0	0	0	29
.336	174	6.9	32.5	0	31.9	N. 41° 09′ E.	48.5	0	0	0	30
.067	4574	2722.6	1029.3	426.3	1164.8	.....	.....	.....	.....	0.29	....
.102	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	....
.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	....

MONTHLY SUMMARY OF

DECEMBER,

DATE.	THERMOMETERS.					PSYCHROMETER.						SUNSHINE REC		
	TEMPERATURES.			Hours of Extremes.		Relative Humidity.			Dew-point.			Clouds at Observations	Number Minute	
	Mean of 24 hrs.	Extremes.				6 A.M.	12 M.	6 P.M.	6 A.M.	12 M.	6 P.M.		Actual.	Possible
		Max.	Min.	Max.	Min.									
1	42.7	64	26	2 p.m.	6 a.m.	67	30	14	17	21	4	0	....	535
2	35.8	56	23	3 p.m.	5 a.m.	67	27	23	17	18	8	8	355	535
3	38.7	61	22	2 p.m.	6 a.m.	71	7	38	22	5	22	0	471	533
4	38.3	60	20	2 p.m.	5 a.m.	64	12	25	13	7	10	0	456	533
5	45.6	58	34	2 p.m.	1 a.m.	30	7	13	13	5	0	6	413	532
6	40.3	51	30	1 p.m.	11 p.m.	25	14	62	5	6	26	6	279	532
7	41.7	56	25	2 p.m.	5 a.m.	60	17	56	18	11	31	7	342	530
8	39.4	47	28	12 m.	10 p.m.	66	22	63	31	11	28	11	134	530
9	30.1	39	20	3 p.m.	12 n't	77	31	52	13	11	16	2	416	528
10	30.2	46	18	2 p.m.	7 a.m.	73	25	46	14	12	15	0	421	528
11	31.3	40	19	2 p.m.	1 a.m.	69	85	83	20	37	31	30	0	528
12	31.0	40	22	2 p.m.	12 n't	90	68	72	28	27	25	19	305	528
13	26.4	36	13	1 p.m.	6 a.m.	93	48	69	12	17	20	8	95†	526
14	27.7	35	15	1 a.m.	12 n't	52	72	56	16	24	14	6	409	526
15	20.0	32	6	2 p.m.	7 a.m.	76	36	39	9	9	3	6	394	526
16	21.6	31	12	2 p.m.	5 a.m.	58	45	51	7	8	8	13	132	526
17	15.2	24	4	3 p.m.	12 n't	72	46	56	5	3	5	2	396	525
18	14.2	30	0	1 p.m.	4 a.m.	87	21	58	5	−3	7	6	367	525
19	20.2	35	5	2 p.m.	4 a.m.	34	25	36	5	5	5	0	424	525
20	26.2	42	5	2 p.m.	2 a.m.	70	23	16	9	8	18	13	270	525
21	28.8	40	20	2 p.m.	9 p.m.	57	24	34	15	6	7	5	231	524
22	36.6	44	18	2 p.m.	2 a.m.	22	44	73	4	21	26	11	339	524
23	32.8	47	18	2 a.m.	12 n't	37	63	67	20	22	17	16	76	525
24	45.1	60	16	1 p.m.	1 a.m.	34	13	11	17	8	2	10	340	525
25	33.5	47	21	11 p.m.	8 a.m.	75	31	34	17	11	7	8	329	525
26	47.7	59	33	4 p.m.	4 a.m.	34	13	25	17	8	20	17	203†	525
27	40.5	52	29	1 a.m.	12 n't	29	56	100	18	25	32	16	310	526
28	29.0	31	24	9 a.m.	11 p.m.	61	81	90	20	26	28	19	50	526
29	31.0	38	21	2 p.m.	12 n't	74	17	21	27	0	−3	5	410	527
30	23.8	35	10	3 p.m.	8 a.m.	55	50	56	3	14	14	0	480	527
31	38.4	52	20	2 p.m.	12 n't	55	47	59	24	29	29	3	460	528
Sums,	1003.8	1388	577	.....	.....	1834	1100	1498	461	412	475	253	....	....
Means,	32.4	44.8	18.6	.....	.....	59	35	48	15	13	15	8	....	....
Perc'g,	.....	.....	.....	.....	.....	....	....	....	....	....	....	27%	....	....

† 13th and 26th, sunshine record incompl

INSTRUMENTAL RECORD.

1907.

[illegible]	ANEMOMETER AND ANEMOSCOPE.							RAIN GAUGE.			
	WIND.							Hours of Fall.		Total Amount.	Date.
[illegible]	Total Velocity.	Sum of Components.				Equivalent.		Earliest.	Latest.		
		N.	S.	W.	E.	Direction.	Miles.				
[illegible]	177	.....	.....	.....	.....	.....	.....	0	0	0	1
[illegible]	135	126.3	0.1	6.0	7.8	N. 0° 49′ E.	126.2	0	0	0	2
[illegible]	149	128.6	6.0	5.9	18.2	N. 5° 44′ E.	123.2	0	0	0	3
[illegible]	121	93.2	17.0	12.8	12.3	N. 0° 23′ W.	76.2	0	0	0	4
[illegible]	124	73.4	33.2	15.7	32.4	N. 22° 34′ E.	43.5	0	0	0	5
[illegible]	188	96.7	61.0	13.8	64.6	N. 54° 54′ E.	62.1	0	0	0	6
[illegible]	134	8.3	19.1	37.5	30.6	N. 6° 08′ W.	64.5	0	0	0	7
[illegible]	327	298.9	0	49.8	24.6	N. 4° 49′ W.	299.9	0	0	0	8
[illegible]	(Total	.....	.....	.....	.....	.....	.....	.....	.....	T	9
[illegible]	for	.....	.....	.....	.....	.....	.....	0	0	0	10
[illegible]	seven	.....	.....	.....	.....	.....	.....	8 a.m.	.....	.05	11
[illegible]	days	.....	.....	.....	.....	.....	.....	.....	.....	.02	12
[illegible]	1723)	.....	.....	.....	.....	.....	.....	0	0	0	13
[illegible]	.....	.....	.....	.....	.....	.....	.....	0	0	0	14
[illegible]	.....	.....	.....	.....	.....	.....	.....	0	0	0	15
[illegible]	130	93.6	7.7	14.7	22.2	N. 4° 59′ E.	68.2	0	0	0	16
[illegible]	241	177.8	30.6	0.8	48.6	N. 17° 59′ E.	154.8	.....	.....	T	17
[illegible]	145	89.3	37.7	3.7	38.6	N. 34° 04′ E.	62.2	0	0	0	18
[illegible]	222	160.7	4.9	119.2	0	N. 37° 25′ W.	196.2	0	0	0	19
[illegible]	170	142.4	16.7	10.7	22.4	N. 5° 19′ E.	126.2	0	0	0	20
[illegible]	221	206.9	0	23.2	30.1	N. 1° 55′ E.	207.0	0	0	0	21
[illegible]	253	190.8	8.7	78.1	46.9	N. 9° 43′ W.	184.8	0	0	0	22
[illegible]	280	247.1	0	73.5	45.4	N. 6° 29′ W.	248.7	10 a.m.	.....	T	23
[illegible]	245	267.9	66.0	287.1	50.9	N. 49° 29′ W.	310.7	0	0	0	24
[illegible]	124	34.4	62.5	18.0	49.8	S. 48° 32′ E.	42.4	0	0	0	25
[illegible]	375	150.8	60.8	242.6	40.1	N. 66° 02′ W.	221 6	0	0	0	26
[illegible]	381	81.5	39.4	268.8	46.1	N. 79° 18′ W.	226.6	11 a.m.	.....	.04	27
[illegible]	181	14.3	118.3	3.0	109.0	S. 45° 33′ E.	148.5	0	0	0	28
[illegible]	302	226.9	5.0	149.3	18.2	N. 30° 34′ W.	257.8	0	0	0	29
[illegible]	110	37.8	32.9	10.8	24.7	N. 70° 35′ E.	14.7	0	0	0	30
[illegible]	145	43.5	36.5	100.3	16.6	N. 85° 13′ W.	84.0	0	0	0	31
[illegible]	6603	2991*1	664.1*	1545*3	800.1*	.....	.....	.....	.....	0.11	....
[illegible]	.....	.....	.....	.....	.....	.....	.....	.....	.....	....	....
[illegible]	.....	.....	.....	.....	.....	.....	.....	.....	.....	....	....

*For 30 days.

ANNUAL SUMMARY, 1907, BY MONTHS.

Month.	Barometer.					Thermometer.							Anemometer.		
	Mean at 12 M.	Extremes.		Dates of Extremes.		Mean.	Extremes.		Dates of Extremes.		Mean Max.	Mean Min.	Wind.		
		Max.	Min.	Max.	Min.		Max.	Min.	Max.	Min.			Mean Daily Velocity	Max. Daily Velocity	Date.
January	23.922	24.33	23.40[2]	22	1	32.6	60	2	23	27	45.2	19.3	199	465	19
February	24.042	.34	.70	10	27	38.5	69	1	8	3	52.6	23.2	197	317	18
March	23.953	.29	.53	30	26	45.3	78	13	18	1	58.3	31.0	246	571	26
April	.979	.27	.73	20	6	43.2	78	12	10	21	54.6	31.2	228	588[1]	7
May	.980	.22	.48	26	12	47.9	80	17	21	3	58.2	37.1	222	452	13
June	24.024	.41[1]	.82	18	8	61.1	87	37	29	1	73.0	47.1	203	340	15
July	.138	.30	.88	30[3]	15	66.9	90[1]	48	23	15	80.4	54.6	171	305	16
August	.148	.29	.95	19	30	65.5	87	44	9[3]	12	79.9	52.6	156	298	11
September	.104	.28	.90	1	19	59.7	83	33	12	10[3]	73.9	45.2	165	328	29
October	.146	.39	.84	9	28	49.8	75	28	6	21	63.3	36.6	174	338	7
November	.102	.34	.77	30	20	36.0	65	6	6[3]	11	50.1	22.0	152	317	18
December	23.943	.31	.50	2	11	32.4	64	0[2]	1	18	44.8	18.6	213	381	27
Sums	288.481	291.77	284.50	.....	.....	578.9	.....	.....	.....	.....	734.3	418.5	2,326	.....	.....
Means	24.040	24.31	23.71	.....	.....	48.2	.....	.....	.....	.....	61.2	34.9	194	.....	.....

Month.	Psychrometer.								Percentages of Cloud and Sun.		Rain Gauge. (Melted snow inclu'd)			Number of Days.						
	Relative Humidity.			Minimum Humidity.[5]		Dew-point.														
	6 A.M.	12 M.	6 P.M.	Per ct.	Date.	6 A.M.	12 M.	6 P.M.	Cloud (Area)	Sunshine (Time)	Total Fall.	Max. in one day.	Date.	Max.Th. below 32°	Min.Th. below 32°	Max.Th. above 80°	Clear.	Part Cloudy	Cloudy	Rain.[4]
Jan.	67	44	48	12	13	16	17	17	32	56	0.11	0.10	1	3	29	0	19	7	5	2
Feb.	62	35	46	7	8	19	17	20	32	63	0.11	0.06	24	3	26	0	14	12	2	3
Mar.	68	39	43	16	19[3]	25	26	28	36	61	0.16	0.14	13	1	18	0	16	12	3	2
April	73	48	56	14	15	27	28	31	52	45	1.58	0.69	20	4	16	0	8	10	12	8
May	76	54	61	16	21	32	35	37	58	28	1.65	0.32	6[3]	0	9	0	4	17	10	9
June	51	29	35	9	8	34	33	37	35	41	0.40	0.20	30	0	0	3	16	10	4	5
July	60	38	43	12	15[6]	45	46	46	42	51	2.11	0.60	26	0	0	17	12	15	4	9
Aug	65	32	47	15	5[3]	45	42	45	43	46	1.91	1.17[1]	1	0	0	17	13	13	5	6
Sept.	65	29	41	8	22	36	34	39	29	65	0.68	0.33	9	0	0	5	19	10	1	4
Oct.	69	33	51	14	2	30	29	35	26	66	0.69	0.39	24	0	2	0	24	5	2	5
Nov.	65	31	49	12	6[3]	17	16	20	21	66	0.29	0.28	10	1	26	0	24	3	3	2
Dec.	59	35	48	7	5[3]	15	13	15	27	59	0.11	0.05	11	4	29	0	21	9	1	3
Sums,	780	447	568	.....	.....	341	336	370	433	647	9.80	.....	.....	16	155	42	190	123	52	58
Means,	65	37	47	.....	.....	28	28	31	36	54	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

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No. 6. The Distribution of Woody Plants in the Pike's Peak Region.—*E. C. Schneider.*

COLORADO SPRINGS, COLORADO

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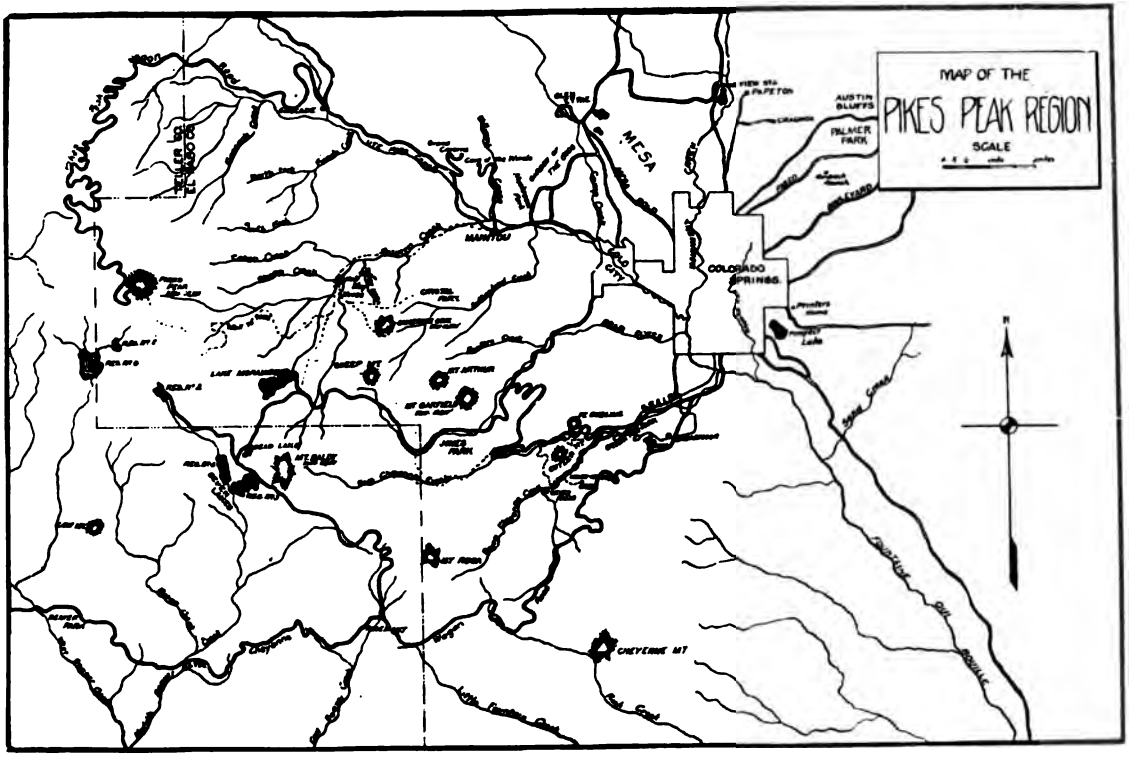
MAP OF THE
PIKES PEAK REGION
SCALE
MESA
COLORADO SPRINGS
AUSTIN BLUFFS
PALMER PARK
MANITOU
ST. PETERS DOME
CHEYENNE MT
N

THE DISTRIBUTION OF WOODY PLANTS IN THE PIKE'S PEAK REGION.

By Professor Edward C. Schneider.

In the November number of the Botanical Gazette (Vol. 44) for 1907 there appeared an article, entitled "The Forest Formations of Boulder County, Colorado," written by Dr. Robert T. Young; and, in December of the same year Dr. Francis Ramaley published a paper, in volume five of the University of Colorado Studies, on "The Silva of Colorado" in which he listed the woody plants of Boulder County. The great value of these two articles has led to the presentation of the present paper.

A large amount of careful study has been given to the plant life of the Pike's Peak region by Prof. F. E. Clements and Dr. Homer L. Shantz. Clements* has drawn many of the illustrations in his two books, "Research Methods in Ecology" and "Plant Physiology and Ecology" from his work on Pike's Peak. Shantz has incorporated his observations in an article entitled "A Study of the Vegetation of the Mesa Region East of Pike's Peak: The Bouteloua Formation.†"

In the present paper no attempt will be made to enter into a detailed study of the physical characters of the habitat of the woody plant. A few observations on the constitution of the soil, on its water content, temperature, etc., have been made, but they appear to me to give little of value for this study. Such detailed field observations, I believe, may best be used at present in the physiological interpretation of the distribution of herbaceous plants. The real object here is to present a picture of the associations of the

*See also "Formation and Succession Herbaria," University Studies of the University of Nebraska, Vol. 4.

†Botanical Gazette, 1906, Vol. 42.

woody plants that may be valuable to students of montane distribution.

Among the variations in climatic conditions within the region studied it may be well to note briefly those of rainfall and temperature. There are decided differences in the amount of annual rainfall. The meteorological records in the Colorado College Observatory give us an opportunity to compare three stations, Colorado Springs, Lake Moraine and the summit of Pike's Peak, with respect to precipitation. Colorado Springs is located on the plains just below the mesa at an altitude of about 6,000 feet, Lake Moraine is three and three-quarter miles southeast of the summit of Pike's Peak at an altitude of 10,215 feet, and the height of the summit of the "Peak" is 14,109 feet. Unfortunately the available records for these stations are not of the same years. However, they cover long enough periods at each altitude to make a comparison worth while. Complete records* for the thirteen years ending 1907 show Colorado Springs to have an average rainfall of 14.79 inches and Lake Moraine an average of 25.32 inches. During the fourteen years, 1874 through 1887, the average annual precipitation on the summit of Pike's Peak was 29.62 inches. The differences in rainfall are, therefore, pronounced enough to influence plant growth.

Dr. F. H. Loud† in a comparison of temperatures at Colorado Springs and Lake Moraine for the year 1906 showed the differences in the monthly means temperature given in the following table:

MONTH.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Lake Moraine	19.6	21.4	21.6	29.2	38.6	46.9	45.9	48.6	42.0	33.4	25.2	25.3
Colorado Springs	32.6	31.3	27.8	45.2	53.9	61.4	62.9	65.5	57.7	46.0	35.3	37.6

In this study of distribution I find it convenient to separate the associations of the woody plants into the following

*Mr. Chester M. Angell, director of the Colorado College weather bureau, kindly gave me the data from which these figures were compiled.

†See Colorado College Publication, Science Series, Vol. XII, No. 4.

groups: (1) The stream bank formation on the plains; (2) The stream bank formation in the lower cañons; (3) The stream bank and meadow formation in the subalpine zone; (4) The woody plants of the plains; (5) The mesa and foothill thickets; (6) The thickets on arid mountain slopes; (7) North slope mountain thickets; (8) Pinon and cedar forests; (9) Yellow pine forests; (10) Douglas spruce forests; (11) Engelmann's spruce and white pine forests; (12) Engelmann's spruce and foxtail pine forests.

THE STREAM BANK FORMATION ON THE PLAINS.

This formation is conspicuous along all streams, beginning at their emergence from the cañons and extends throughout the course in the foothills and plains. The woody plants occupy a narrow strip of the bank on either side and reach a maximum in numbers and in size in the alluvial deposits of the stream. They are unevenly distributed, the higher bank being often devoid of woody plants while the lower bank is densely covered with a grove of trees or a thicket of shrubs. The entire formation is open. The cottonwoods and willows are the most numerous, and, therefore, the dominant species. Usually the cottonwood trees are separated far enough to permit a scattered undergrowth of less important species. Dense but limited thickets of the plum (*Prunus americana*), the skunk bush (*Rhus trilobata*), or the wolf berry (*Symphoricarpos occidentalis*) are frequent in open places and may occur away from the stream. Nearer the mountains the choke cherry (*Prunus melanocarpa*) often is found in clumps, and roses may form briar patches. Along Cheyenne Creek, on the flood plains, occur a few patches of the false indigo (*Amorpha fruticosa*). The oak thickets also frequently enter this formation from the sides in the foothills.

The dominant species within the formation are:

Populus occidentalis.	Salix fluviatilis.
Populus angustifolia.	Salix amygdaloides.
Populus acuminata.	Salix monticola.

Other species named in the order of frequency are:

Rhus trilobata.	Rhus Rydbergii.
Symphoricarpos occidentalis.	Rosa spp.
Prunus melanocarpa.	Quercus spp.
Prunus americana.	Physocarpus intermedius.
Salix irrorata.	Amorpha fruticosa.
Salix Bebbiana.	Bossekia deliciosa.
Clematis ligusticifolia.	Cornus stolonifera.
Ribes longiflorum.	Alnus tenuifolia.

The dominant species are not distributed equally throughout the formation, thus *Populus occidentalis* is most abundant at the lower levels and is largely supplanted at the higher altitudes by *P. angustifolia*. *Salix fluviatilis* and *S. amygdaloides* are abundant throughout, while *S. monticola* first appears within a few miles of the cañons. *S. irrorata* and *S. Bebbiana* are common only near the cañons. *Ribes longiflorum*, *Amorpha fruticosa* and *Prunus americana* are found almost exclusively within this formation. Gymnosperms do not normally occur here.

THE STREAM BANK FORMATION OF THE LOWER CANONS.

This formation as a rule comprises a very narrow strip along both banks of the stream. Yet in low, wide cañons and where a narrow cañon bottom widens enough to permit an accumulation of alluvial soil, it may be considerably enlarged. It is often closely hemmed in on the two sides by forests or thickets that are invading the cañon bottom from the walls.

The transition from the lower formation to this is gradual. Many species are common to both near the mouth of the cañon. Some of the willows, characteristic of this formation, extend in decreasing numbers plainward, while the *Pop-*

ulus angustifolia so prominent in the preceding formation, even though it occurs as high as 8,500 feet, is so scattered that it cannot be considered a dominant species.

The dominant species are rarely more than shrubs. An individual, outside the gymnosperms and the aspen, exceeding a height of twenty feet is uncommon.

The dominant species of this formation are:

Salix Bebbiana.
Salix irrorata.
Salix monticola.
Populus tremuloides.
Betula fontinalis.

Other species occurring within the formation follow:

Pseudotsuga mucronata.
Abies concolor.
Picea Parryana.
Corylus rostrata.
Physocarpus intermedius.
Prunus melanocarpa.
Prunus pennsylvanica.
Salix fluviatilis.
Bossekia deliciosa.
Jamesia americana.
Acer glabrum.
Rosa spp.
Holodiscus dumosa.
Quercus spp.
Rhus Rydbergii.
Salix amygdaloides.
Salix flava.
Ribes saxosum.
Ribes leptanthum.
Cornus stolonifera.
Symphoricarpos occidentalis.
Symphoricarpos racemosus pauciflorus.
Parthenocissus vitacea.
Sorbus scopulina.
Sambucus microbotrys.
Viburnum pauciflorum.
Lonicera involucrata.
Ribes lentum.
Alnus tenuifolia.

It will be noted that this formation contains a greater number of species of woody plants than the lower one. There are also more differences among the dominant and conspicuous species of the several cañons studied. Thus along the Cheyenne Creeks and Rock Creek the wild red cherry (*Prunus pennsylvanica*) is so abundant that it becomes one of the dominant species. In the Cheyenne Cañons and Sutherland

Cañon the beaked hazel (*Corylus rostrata*) ranks with the dominant forms and in Ute Pass, along Fountain Creek and the tributaries of this stream from the west, the alder (*Alnus tenuifolia*) is a dominant species. Furthermore, the alder is rarely found elsewhere. The fly honeysuckle, also, is found exclusively in this formation along the west tributaries of the same stream in Ute Pass. The aspen (*Populus tremuloides*) is very unevenly distributed. Occasionally it forms dense groves of large trees the crowns of which so shade the floor that all other species are destroyed. It is usually scattered within the entire formation. The mountain ash (*Sorbus scopulina*) is only abundant in Buffalo Cañon where it forms an occasional dense clump. The elder (*Sambucus microbotrys*), *Ribes lentum*, the few flowered cranberry (*Viburnum pauciflorum*) and *Rosa Engelmannii* normally appear only in the higher altitudes. Willows, the most constant of the dominant shrubs, are scarce along those streams arising high on Mt. Rosa.

Although gymnosperms occur widely distributed in this formation, many of them, such as the yellow pine (*Pinus scopulorum*), white pine (*Pinus flexilis*) and Engelmann's spruce (*Picea Engelmanni*) must be considered invaders from the forests of the mountain slopes and cañon walls. The white fir (*Abies concolor*), which is often abundant in the lower cañons, prefers moist cañon bottoms. Here it reaches its greatest size and most perfect form. Also the blue spruce (*Picea Parryana*), ranging from 7,000 to 9,500 feet, appears best adapted for cañon life. The white fir and blue spruce may well then be regarded as members of this formation.

THE STREAM BANK AND MEADOW FORMATION OF THE SUBALPINE ZONE.

The highest development of this formation is found in the wide meadows and bogs occurring along the subalpine streams. It is a closed formation only in these meadows and bogs.

Very often the characteristic species are greatly scattered and among them may be invading forms derived from the slopes along the stream. Among these invaders are the white pine, foxtail pine (*Pinus aristata*), Engelmann spruce, squaw currant (*Ribes cereum*), *Physocarpus monogynus*, and *Holodiscus dumosa*.

The dominant species range from timber line to as low as 8,700 feet. They are low shrubs that seldom reach a height of nine feet. The aspen is the only broad leaved tree at this altitude. It will also be observed that the number of species here is far less than in the formation just below.

The dominant species are:

Salix glaucops.	Salix monticola.
Salix chlorophylla.	Betula glandulosa.
Salix Bebbiana.	Dasiphora fruticosa.

Other species within the formation are:

Populus tremuloides.	Rosa spp.
Ribes saxosum.	Jamesia americana.
Ribes lentum.	Prunus melanocarpa.
Sambucus microbotrys.	

Salix Bebbiana and *S. monticola* are very abundant in the lower part but gradually decrease in number and size toward the middle of the formation, and they are finally replaced by *S. glaucops* and *S. chlorophylla*. The shrubby cinquefoil (*Dasiphora fruticosa*) and the elder berry are at their best here and decrease in importance as they pass down into the lower formation.

THE WOODY PLANTS OF THE PLAINS.

There are very few true woody plants on the plains. Several species named in this paper are only suffrutescent. The conditions of life are so xerophytic that woody plants when present are widely separated. The pasture sage brush or wormwood (*Artemesia frigida*) is most abundant and

rather evenly distributed. The woody eriogonum (*Eriogonum effusum*), the toothed-leaved primrose (*Meriolix serrulata*), gutierrezia (*Gutierrezia sarothrae*), and the rabbits bush (*Chrysothamnus graveolens*) may easily be found but they are not nearly so common as the sage. Occasionally the prairie rose (*Rosa arkansanna*) occurs in very restricted patches. The most conspicuous and often the largest of the plains' woody plants is the winter fat (*Eurotia lanata*). It is abundant over limited areas.

THE MESA AND FOOTHILL THICKETS.

These thickets vary greatly in density, width and species. Along the base of the mountains they have the greatest variety of forms and the maximum size. As they reach out on the mesa they become more open and finally on those arms of the mesa that extend the more eastward onto the plains, they are represented by straggling individuals of the mountain mahogany (*Cercocarpus parvifolius*). On the eastern part of the mesa the thicket is confined to the ridges and gullies, where it alternates sharply with the grass formation.

The dominant species are:

Quercus utahensis.	Quercus Gambellii Fendleri.
Quercus Gunnisonii.	Cercocarpus parvifolius.
Quercus Gambellii.	Rhus trilobata.

Other species found in the thickets are:

Ribes cereum.	Clematis ligusticifolia.
Symphoricarpos occidentalis.	Eriogonum effusum.
Quercus Vreelandii.	Artemesia frigida.
Atriplex canescens.	Gutierrezia sarothrae.
Eurotia lanata.	Chrysothamnus graveolens.
Rosa spp.	Rhus Rydbergii.
Prunus melanocarpa.	Rhus cismontana.
Prunus pennsylvanica.	Crataegus spp.
Bossekia deliciosa.	Ceanothus mollissunus.
Holodiscus dumosa.	Ribes leptanthum.
Holodiscus australis.	

There are no oaks on the eastern edge of the mesa. Shantz attributes this to the effects of grazing. Oaks increase in numbers as the mountains are approached. They form small isolated clumps two and three miles from the mountains which increase in size to broad thickets nearer the mountains. Usually the larger oaks are near streams and near or on some of the moist lower mountain slopes. Often the thickets of taller oaks have an undergrowth of roses, wolf berry, and poison ivy. At intervals the western virgins bower (*Clematis ligusticifolia*) is common and an occasional choke cherry and wild red cherry is found.

The oaks are associated with the mountain mahogany (*Cercocarpus parvifolius*) on dry slopes. In this association the Cercocarpus is ordinarily more abundant toward the crest of ridges, while the oaks increase in numbers down the slope.

The unsavory raspberry (*Bossekia deliciosa*) and meadow-sweet (*Holodiscus dumosus*) are never abundant. They come down from the mountains and disappear from the thickets a very short distance from the lower mountain slopes or from a stream. The haws (*Crataegus*) may occur in clumps in draws or scattered within an oak thicket. The red root (*Ceanothus mollissunus*) is frequently a part of the undergrowth.

It will be observed that all of the woody plants of the plains are found among the foothill thickets. They are present in every locality.

The appearance of the thickets changes along the eastern limits of the mesa. Here the *Cercocarpus parvifolius* and *Rhus trilobata* are the dominant forms. *Rhus trilobata* shows a disposition to form dense clumps which reach their greatest development in the draws and gullies. Toward the ridges they are reduced in numbers and more scattered. The *Cercocarpus parvifolius* prefers the ridges and the top of the mesa, and the individual shrubs are found widely separated. This

shrub seems to be the strongest invader of these thickets. "Along the ridges north and east of Colorado Springs there is certain evidence that the thicket formation is slowly pushing its way out into the grass formation. Of the shrubs, Cercocarpus parvifolius seems best adapted for this invasion, and it is several miles in advance of any of the other dominant species."* Throughout the mesa, shrubs appear on both the north and south slopes of the gullies showing only a slight preference for the north slopes.

The squaw currant (*Ribes cereum*) occurs in the gullies associated with the *Rhus trilobata*. The wolf berry is found in the draws and gullies, forming distinct patches. Here and there may be found a lone yellow pine.

Shantz has called attention to the effects of grazing. "Wherever cattle are allowed to crop the thicket formation very closely, the facies (dominant species) are completely killed. This is the more noticeable in the case of the oaks, which are killed by the entire loss of chlorenchyma tissue. They are attacked by cattle before any of the other facies of the thicket formation. An examination of the region shows that on the mesa near Colorado City the thicket formation has been replaced almost entirely by the Bouteloua (grass) formation. Only scattered bushes of Cercocarpus parvifolius and Rhus trilobata are found, and these much reduced in size. Grazing changes the thicket formation to a grass formation."

THICKETS ON ARID MOUNTAIN SLOPES.

South exposures are invariably xerophytic. They are exposed to the action of the sun's rays the entire year, hence evaporation is greater than on north exposures where the snows of the winter accumulate and remain until late into the spring, or in the higher mountains even into early summer. Throughout the summer, even though conditions are more nearly equal on north and south slopes, the excess of evapora-

*See Shantz Botanical Gazette, Vol. 42, p. 192.

tion is still on the south slopes. The conditions of plant life are, therefore, similar to those experienced in the foothill thickets. This accounts for the presence of the woody plants common to the lower thickets.

These mountain thickets are, as a rule, more open than lower thickets. They often reach an altitude of 9,500 feet. In the upper limits the shrubs are most widely separated. The oaks are not present above 9,000 feet. The *Rhus trilobata* disappears as low as 7,500 feet but the *Cercocarpus parvifolius* continues throughout the entire area. The meadowsweet and the unsavory raspberry are somewhat more abundant. Three new woody plants appear for the first time in these high thickets, these are the Colorado ninebark (*Physocarpus monogynus*), wax flower (*Jamesia americana*), and the kinnikinic (*Arctostaphylos uva-ursi*).

Widely scattered trees, invaders from nearby forest, are to be expected. Among these are *Pinus edulis, Juniperus scopulorum, Pinus scopulorum* and *Pinus flexilis.*

NORTH SLOPE MOUNTAIN THICKETS.

These Clements has designated as the "half gravel slide formation." The environment is more favorable to plant life hence there is a greater variety of species than is found on the south slopes. The conditions also favor tree growth, so the formation is usually being vigorously invaded by forest forms from above and along the sides. There is a greater crowding together of the inhabitants than on the south slopes, but the formation is still more or less open.

The dominant species are:

Physocarpus monogynus.
Bossekia deliciosa.
Jamesia americana.
Holodiscus dumosus.
Holodiscus australis.
Clematis pseudoalpina.
Acer glabrum.

Other species that may occur are:

Rhus trilobata.	Symphoricarpos racemosus pauciflorus.
Prunus melanocarpa.	Juniperus sibirica.
Prunus pennsylvanica.	Salix Nuttallii.
Rubus strigosus.	Quercus spp.

Seldom does a maple (*Acer glabrum*) occur near the top; it is found in greater numbers on the lower part of the slope near the cañon bottom. The red raspberry (*Rubus strigosus*) is confined to the more open spaces, and the snow berry (*Symphoricarpos*) is almost exclusively confined to the slope at the cañon bottom. Oaks are never common. Often near the top the *Cercocarpus parvifolius* enters from its normal formation on the opposite side of the ridge.

In addition to the trees found invading the south slopes are the Douglas spruces and the white firs; these usually outnumber the pines. The aspen is also a common invader.

THE PINON AND CEDAR FORESTS.

Clements speaks of this as the "foothill woodland." It occupies a zone at the base of the mountains and is well developed only in a restricted area. This tract includes a portion of the Garden of the Gods, Black Cañon, the lower part of William's Cañon, and the hills back of Manitou. It is most highly developed in Black Cañon. East of Ute Pass near Woodland Park the same formation is found on lime ridges. Here and there isolated members of these forests may be found along the base of the mountain range. A small remnant remains on Cutler Mountain.

Shantz found evidence, eleven miles east of Colorado Springs, which indicated that members of these forests formerly extended plainward. "*Juniperus monosperma* is scattered here and there, and isolated trees of this species are often found which seem to be very old. Still stronger evidence is found in the fact that here, many miles removed from its

fellows, is a very large and apparently very old *Pinus edulis*. Erosion has removed the soil from the base of the tree, exposing the roots, and it is certainly much older than any of the other trees in this region. It is the only tree which supports a rich lichen flora."

These forests are so open that the typical members are mixed throughout with the dominant species of the foothill thickets. The shrubs follow the same distribution found in the pure thickets. The dominant species of the "woodland" occur equally on north and south slopes. Often near the crests of ridges the pinon pine (*Pinus edulis*) is the lone representative of the trees.

The dominant species of these forests are:

Pinus edulis.	Cercocarpus parvifolius.
Juniperus scopulorum.	Quercus spp.
Juniperus monosperma.	

Other species often present are:

Pinus scopulorum.	Rosa spp.
Pseudotsuga mucronata.	Gutierrezia sarothrae.
Holodiscus dumosus.	Artemesia frigida.
Eurotia lanata.	Prunus melanocarpa.
Atriplex canescens.	Ribes cereum.
Rhus trilobata.	Symphoricarpos occidentalis.

The yellow pine comes in from a higher forest and is never very conspicuous here. The Douglas spruce is very uncommon in the formation. The entire formation presents a striking and unusual appearance due to the free branching of its three dominant tree species. Very few of these trees present a well formed trunk, they usually form low round topped spreading trees.

THE YELLOW PINE FORESTS.

There is a gradual transition from the typical south slope thicket formation to the yellow pine forest. The habitats of

the two are practically identical. In the immediate Pike's Peak region these forests do not reach the perfection found elsewhere. Some of the better examples occur near Woodland Park and in Manitou Park. The forest is very open. Its dominant species is the yellow pine (*Pinus scopulorum*) and associated with it are the woody plants of the south slope thicket. The kinnikinic is a constant member of the formation. The white pine associates with the yellow pine at about 7,800 feet and at higher elevations often outnumbers it.

This forest formation extends over a greater area than any other of our forests. It may occur above 9,000 feet and arms of it stretch far out on the plains. Pound and Clements* have shown that it has pushed its way eastward into Nebraska. The yellow pine is a representative of western conifers sometimes found mingling in Nebraska with trees from the eastern forests.

THE DOUGLAS SPRUCE FORESTS OF THE NORTH SLOPES.

These forests may be found up to an altitude of 9,500 feet on the cool, moist north slopes. They constitute the most familiar forests of our mountains. They vary some in closeness and in species. As a rule they are open enough to permit the growth of one or two lower layers of woody plants. Some, however, have no undergrowth. Young,† writing of similar forests, states, "This is not to be explained alone on the ground of a scarcity of light or of moisture, but rather by the combined absence of these factors. The shade is seldom dense enough to exclude shade loving plants, were sufficient moisture present to satisfy the needs of such forms."

The most abundant tree is the Douglas spruce, and always mingling intimately with it is the yellow pine. These two, together with the white fir and an occasional white pine, form the canopy of the forest. The white fir is confined to moist

*Pound and Clements: Phytogeography of Nebraska.

†Young, R. T.: Botanical Gazette, Vol. 44, p. 338.

slopes and occurs in greater numbers in the draws. The aspen is often freely distributed among the conifers and may unite with them in forming the canopy. More frequently it forms a second story.

Below the canopy scattered shrubs of *Bossekia deliciosa, Holodiscus dumosus, Jamesia americana, Acer glabrum, Prunus melanocarpa,* and *Salix Nuttalii,* all of which are common in north slope thickets, form a second layer, and below these will be found forms that are normally a part of these forests. These are the dwarf juniper (*Juniperus siberica*), the Colorado nine-bark (*Physocarpus monogynus*) the purple virgin's bowers (*Clematis pseudoalpina* and *C. pseudoalpina tenuiloba*), and the kinnikinic. The *Physocarpus monogynus* prefers the open spaces. Often in larger openings the *Rubus strigosus* thrives. The *Clematis pseudoalpina tenuiloba* is by far the most abundant species below the canopy. The very varied undergrowth is well developed only in the thin forest.

On the lower part of these forested slopes, near the moist cañon bottom, the snow berry thrives.

THE ENGLEMANN SPRUCE AND WHITE PINE FORESTS.

These forests extend from about 9,500 feet to 10,400 feet and form some of our most luxuriant growths. Clements has included this and the Douglas spruce forests in his "*Picea-Pseudotsuga*" formation. The passage from the lower Douglas spruce forest to this higher forest is a gradual transition, hence, the dominant species of each extensively overlap.

The dominant species are:

Picea Engelmanni.	Pinus flexilis.

Less important species are:

Populus tremuloides.	Arctostaphylos uva-ursi.
Salix Nuttalii.	Juniperus siberica.
Salix Bebbiana (rare).	Rubus strigosus.

Often the forest contains the dominant species only, then the floor is bare. The undergrowth is never important. If the forest is open the aspen may form dense societies in the intervals. Much of this virgin forest has been destroyed by fire. In the process of reforesting the denuded areas the aspen becomes the dominant form. It is, however, later gradually reduced in prominence by a slow invasion of the conifers.

THE ENGELMANN SPRUCE AND FOXTAIL PINE FOREST.

Extending from the last forests to timber line is a forest formation that gradually thins out as the upper limit is approached. The dominant species, the Engelmann spruce and the foxtail pine (*Pinus aristata*), are, as a rule, equally abundant. The aspen, so common in the lower forests, early drops out here. Few woody species endure the rigor of this habitat, they are *Ribes lentum, Dasiphora fruticosa, Juniperus siberica* and *Salix Nuttalii*.

The distribution of the woody plants is largely controlled by available moisture and by the temperature of the soil and atmosphere. That moisture is a determining factor is suggested from a study of cross sections of the cañons. Sutherland Creek Cañon offers a very satisfactory field for such a study. Where the stream passes through the mesa the cañon is wide and low, and here the stream flows almost due north. On the east mesa top occurs a typical open mesa-foothill thicket in which low shrubby oaks predominate and an undergrowth is scant or absent. Down this side of the cañon the thicket is more luxuriant and the oaks gradually increase in size as the stream is approached, finally often attaining the size of small trees. A heavy undergrowth of roses, wolf berry, and poison ivy comes in. Along both banks of the creek is the stream bank formation rich in willow, birch, and cottonwood. Passing away from the stream on the opposite side and reaching up on the mesa is an oak thicket similar to that on the east side. On this side it is more open because

there is less available water. Moisture determinations, that I shall not record at this time, made across the cañon at this point seem to support this statement.

Further up the cañon the stream flows almost east. Here on the south side, on the north slopes, the typical thickets of north exposure and the mixed thicket and Douglas spruce forest are well established. Crossing from these slopes to the opposite side one passes through a normal stream bank formation into a splendid example of the xerophytic south slope thicket.

The influence of moisture is also strikingly shown in the alternation of forests. Numerous illustrations of this may be found. A view of a series of approximately parallel ridges extending from west to east often shows the typical open pine forest on the south exposures and the more dense dark Douglas spruce forest on the north exposures.

The influence of temperature is suggested in the distribution of the conifers. Thus the Douglas spruce so abundant at the lower altitudes is replaced by the Engelmann spruce at the higher elevations. The white pine drives out the yellow pine at middle elevations, only to give way to the foxtail pine at still higher levels.

LIST OF SPECIES OF WOODY PLANTS.

The following list contains the distribution of woody plants known to the writer. It will be observed, however, that some species cited by Dr. P. A. Rydberg*, but not known to me, have been included and proper credit given. It has been impossible to give more than a representative distribution for each form. The altitudes given are those I have found, and, therefore, are subject to correction. Throughout the entire paper I have used the names which will appear in Professor Aven Nelson's† new Manual of the Rocky Moun-

*Flora of Colorado, Bulletin 100, The Agricultural Experiment Station of the Colorado Agricultural College.

†I am greatly indebted to Professor Nelson of the University of Wyoming, for the numerous favors shown me in this work and for his kindness in furnishing me the names to be used in his new manual.

tain flora and have also given, in italics, Dr. Rydberg's name in cases of disagreement.

The study of the oaks and the composites is not complete and, therefore, unsatisfactory.

There are 115 species recorded in the list.

PINACEÆ, PINE FAMILY.

Pinus edulis Engelm. PINON PINE, NUT PINE.

A low spreading tree with a short trunk usually branched near the ground. There are two leaves in each bundle. The cones are short, hardly two inches long, with the exposed portion of the scale very thick. Seeds edible. Common in the foothills.

Altitude: 5,800–9,100 feet. Distribution: Cutler Mountain; Williams' Cañon; Garden of the Gods; Black Cañon; Hills back of Manitou; Buffalo Cañon; Blair Athol; Ute Pass; Crystola; Rock Creek.

Pinus scopulorum (Engelm.) Lemmon. YELLOW PINE, ROCK PINE.

A large tree, with stout branches, widely distributed in the mountains and foothills, sometimes reaching out onto the plains. The leaves are from three to six inches long, two or three in a bundle, and grouped in dense bunches at the ends of the branches. The cones are from two and one-half to four inches long, with scales bearing a sharp, recurved prickle.

Altitude: 5,800–10,250 ft. Distribution: Mt. Rosa; Williams' Cañon; Cheyenne Cañons; Stratton Park; Cheyenne Mountain; Sutherland Cañon; Buffalo Cañon; Cheyenne Creek; Cameron's Cone; Austin Bluffs; Cascade Cañon; Crystal Park.

Pinus aristata Engelm. FOX-TAIL PINE, HICKORY PINE.

The branches are stout and whorled. The needles are from 1 to 1½ inches long, five in a bundle, and crowded on the smaller branches in brush-like tufts. The cones are about three and one-half inches long, having scales tipped with long, slender, recurved spines.

Altitude: 10,250–11,500 ft. Distribution: Clyde; Seven Lakes; North French Creek; Mt. Rosa; Pike's Peak; Mt. Garfield; Bald Mountain.

Pinus flexilis James. (*Apinus flexilis* (James) Rydb.) ROCKY MOUNTAIN WHITE PINE, LIMBER PINE.

A tree of wind swept mountains. The branches are tough and flexible. The leaves are in bundles of five. The cones are from 3 to 5 inches long, having scales that are broad, smooth, and thickened at the tips.

Altitude: 6,500–10,500 ft. Distribution: Cheyenne Cañons; Cheyenne Mountain; Pike's Peak; Buffalo Cañon; Clyde; Lake Moraine; Ruxton Creek; Crystola; Cameron's Cone; French Creek; Cascade Cañon; Crystal Park; Mt. Rosa; Bald Mountain.

Pinus Murrayana Oreg. Com. LODGE POLE PINE, BLACK PINE.

The writer knows of but two specimens in the region studied. Distribution: On the ridge between Cameron's Cone and Mt. Garfield at an altitude of 10,350 feet.

Pinus monophylla Torr. and Frem. (*Caryopitys monophylla* (Torr. and Frem.) Rydb.) PINON PINE.

Not known to the writer. Distribution: "Manitou." (Rydberg)

Picea Parryana (Andree) Sarg. BLUE SPRUCE, COLORADO SPRUCE, SILVER SPRUCE.

A conical tree common along streams. The leaves are rigid, four-angled, sharp pointed, and usually covered with a bluish bloom. The needles of both this tree and the Engelmann Spruce are attached to a short stalk which remains after the needle has fallen, leaving the branch rough. It is the State tree of Colorado and preferred for ornamental planting. The cones are clustered, drooping, and occur in the upper part of the tree. They are from 2½ to 5 inches long.

Altitude: 7,000–10,000 ft. Distribution: Crystola; Cameron's Cone; Rock Creek; Crystal Park; Buffalo Cañon; Cascade Cañon; French Creek; Catamount Creek.

Picea Engelmanni (Parry) Engelm. ENGELMANN SPRUCE, WHITE SPRUCE.

A large tree forming forests in the higher mountains. At timber line it is often distorted and matted. The young twigs are pubescent. The leaves are blunt and when crushed emit an offensive odor. The cones are solitary and from 1½ to 2 inches long.

Altitude: 8,200–11,500 ft. Distribution: Clyde; Buffalo Cañon; Seven Lakes; French Creek; Cascade Cañon; Mt. Rosa; Pike's Peak; Bald Mountain.

Abies concolor Lindl. WHITE FIR, SILVER FIR.

A large, handsome tree along mountain streams. Branches frond-like and foliage a silvery green. The leaves are flat and from 1½ to 2½ inches long. The erect cones, 3 to 5 inches long, grow in the top of the tree and have scales that fall away at maturity.

Altitude: 6,800–9,300 ft. Distribution: Williams' Cañon; Cheyenne Cañons; Mt. Rosa; Sutherland Cañon; Buffalo Cañon; Cameron's Cone; Crystal Park; Rock Creek; Ruxton Creek; Manitou.

Pseudotsuga mucronata (Raf.) Sudw. DOUGLAS SPRUCE, RED FIR.

A large tree, with slender twigs, common in cañons and on north slopes. The leaves are soft, flattened, petioled, and blunt pointed. The cones are from 2 to 4 inches long and may be recognized by the fringe-like, three-pointed bracts growing from between the scales.

Altitude: 6,300–10,300 ft. Distribution: Williams' Cañon; Cheyenne Cañons; Cutler Mountain; Cheyenne Mountain; Sutherland Cañon; Buffalo Cañon; Blair Athol; Ute Pass; Cameron's Cone; Crystal Park; Mt. Rosa; Pike's Peak.

Juniperus scopulorum Sarg. (*Sabina scopulorum* (Sarg.) Rydb.) RED CEDAR, ROCKY MOUNTAIN JUNIPER.

When perfect it forms a low, round topped tree with the trunk usually divided near the base. The leaves are a bluish green, often covered with a bloom. The fruit is several seeded. In foothills and lower cañons.

Altitude: 5,800–8,200 ft. Distribution: Williams' Cañon; North Cheyenne Cañon; Ute Pass; Blair Athol; Austin Bluffs; Hills near Manitou; Rock Creek; Sutherland Cañon; Black Cañon; Garden of the Gods; Red Rock Cañon.

Juniperus monosperma Sarg. (*Sabina monosperma* (Engelm.) Rydb.) ONE-SEEDED JUNIPER.

On the eastern foothills. Usually irregular in shape. The leaves are a yellowish green. The fruit usually contains a single seed. Associated with the pinon pine in Black Cañon and the Garden of the Gods.

Altitude: 5,800–7,500 ft. Distribution: Red Rock Cañon; Garden of the Gods; Black Cañon; Williams' Cañon; Ute Pass; Hills near Manitou.

Juniperus sibirica Burgsd. DWARF JUNIPER, MOUNTAIN or LOW JUNIPER.

A low, prostrate shrub. The leaves are awl-shaped, sharp-pointed, grooved, and white lined beneath.

Altitude: 6,500–11,500 ft. Distribution: Clyde; French Creek; Cascade Cañon; Crystal Park; Mt. Rosa; Cheyenne Cañons; Sutherland Cañon; Cheyenne Mountain; Buffalo Cañon; Crystola; Lake Moraine; Ruxton Creek; Cameron's Cone; Pike's Peak; Bald Mountain.

Juniperus communis L.

Distribution: "Minnehaha; Colorado Springs." (Rydberg).

Sabina prostrata (Pers) Antoine. CREEPING JUNIPER, TRAILING SAVIN.

This and the preceding one were not found here by the writer. Distribution: "North Cheyenne Cañon." (Rydberg).

SALICACEÆ, WILLOW FAMILY.

Populus tremuloides Michx. ASPEN, AMERICAN ASPEN, QUAKING ASPEN.

Growing on moist mountain sides and in cañons.

Altitude: 6,300–10,400 ft. Distribution: Cheyenne Cañons; Sutherland Cañon; Cheyenne Mountain; Pike's Peak; Buffalo Cañon; Blair Athol; Clyde; Lake Moraine; Seven Lakes; Crystola; Ruxton Creek; French Creek; Cascade Cañon; Cather Springs; Crystal Park; Mt. Rosa; Bald Mountain.

Populus angustifolia James. NARROW LEAF COTTONWOOD.

Common along streams in the lower mountains and plains.

Altitude: 5,300–8,500 ft. Distribution: Ute Pass; Williams' Cañon; Cheyenne Cañons; Sutherland Cañon; Manitou; Cheyenne Creek; Austin Bluffs; Hills near Manitou; Fountain Creek; Rock Creek; Monument Creek.

Populus acuminata Rydb. RYDBERG'S COTTONWOOD.

Location about the same as P. angustifolia.

Altitude: 5,300–6,500 ft. Distribution: Williams' Cañon; North Cheyenne Cañon; Manitou; Austin Bluffs; Hills near Manitou; Fountain Creek; East of Cheyenne Mountain.

Populus Wislizeni (S. Wats.) Sarg. WISLIZENUS COTTONWOOD.

Along streams. Not very common.

Altitude: 5,800–7,000 ft. Distribution: Williams' Cañon; Cheyenne Creek; Austin Bluffs.

Populus occidentalis (Rydb.) Britton. (*Populus Sargentii* Dode.) COMMON WESTERN COTTONWOOD.

Common along streams on the plains.

Altitude: 5,300–7,000 ft. Distribution: Cheyenne Creek; Fountain Creek; Monument Creek.

Salix amygdaloides Anders. PEACH LEAF WILLOW, ALMOND LEAF WILLOW.

A tree with slender, drooping branches. Common along streams on the plains.

Altitude: 5,300–7,000 ft. Distribution: Austin Bluffs; Williams' Cañon; Manitou; Monument Creek; Fountain Creek; Sutherland Cañon; Cheyenne Creek.

Salix monticola Bebb.

One of the most abundant willows. Recognized by its large, oblong-lanceolate leaves and conspicuous stipules.

Altitude: 5,800–10,000 ft. Distribution: Ute Pass; Williams' Cañon; Cheyenne Creek; Crystola; Cheyenne Cañons; Manitou; French Creek; Fountain Creek; Cather Springs; Rock Creek; Sutherland Cañon; Crystal Park; Ruxton Creek; Bear Creek; Middle Beaver Creek.

Salix fluviatilis Nutt. SAND BAR or RIVER BANK WILLOW.

A low shrub with slender, erect branches and a narrower leaf than any other variety. Along streams near cañon mouths and on the plains.

Altitude: 5,300–7,500 ft. Distribution: Rock Creek; Williams' Cañon; Austin Bluffs; Cheyenne Cañons; Manitou; Fountain Creek; Cheyenne Creek; Sutherland Cañon; Bear Creek.

Salix exigua Nutt. NARROW LEAF WILLOW. "Colorado Springs." (Rydberg).

Salix irrorata Anders.

Growing along streams in the lower cañons and recognized by the beautiful glaucous bloom on its twigs.

Altitude: 6,000–7,900 ft. Distribution: Austin Bluffs; Williams' Cañon; Cheyenne Creek; Manitou; Crystola; North Cheyenne Cañon; Stratton Park; Fountain Creek; Rock Creek; Sutherland Cañon.

Salix Bebbiana Sarg. BEBB'S WILLOW.

(Rydberg divides this into two species: *S. Bebbiana and S. perrostrata*).

A very scraggy topped willow and one of the most common of the region.

Altitude: 5,300–10,000 ft. Distribution: Williams' Cañon; Cheyenne Creek; Buffalo Cañon; Cheyenne Cañons; Clyde; Mt. Rosa; Seven Lakes; Ruxton Creek; Crystola; French Creek; Cascade Cañon; Cather Springs; Rock Creek; Sutherland Cañon; Crystal Park; Bear Creek; Bald Mountain.

Salix flava Rydb. (*Salix Watsoni* (Bebb.) Rydb).

Altitude: 6,000–7,000 ft. Distribution: Williams' Cañon; Ute Pass; Crystola; North Cheyenne Cañon; Rock Creek; Bear Creek.

Salix curtiflora Anders. (*Salix pseudocordata* Anders.)

A willow not common in this region.

Altitude: Up to 9,800 ft. Distribution: Clyde; Rock Creek; "Manitou and South Cheyenne Cañon" (Rydberg.)

Salix Nuttallii Sarg. NUTTALL'S WILLOW, BLACK WILLOW.

Growing on the partially wooded slopes of the mountains.

Altitude: 7,000–11000 ft. Distribution: Clyde; Trail to Crystal Park; Buffalo Cañon; Cheyenne Cañons; Lake Moraine; Ruxton Creek; French Creek; Crystola; Cascade Cañon; Cather Springs; Sutherland Cañon; Crystal Park; Mt. Rosa; Bald Mountain; Cameron's Cone.

Salix Geyeriana Anders. GEYER'S WILLOW. (Rydberg divides this into two species: *Salix Geyeriana* and *Salix macrocarpa*).

A willow with narrow leaves that are silky beneath. Twigs usually covered with glaucous bloom. Uncommon here.

Altitude: 8,000–10,000 ft. Distribution: Clyde; Cascade Cañon; Rock Creek.

Salix glaucops Anders. BOG WILLOW.

(Rydberg divides this into two species: *Salix glaucops* and *Salix pseudolapponum*).

Common in the high altitudes. Leaves grayish on both sides.

Altitude: 8,500–11,500 ft. Distribution: Clyde; Lake Moraine; Seven Lakes; Ruxton Creek; French Creek; Cascade Cañon; Mt. Rosa; Mountain View; Bald Mountain; Pike's Peak.

Salix chlorophylla Anders. GREEN-LEAVED WILLOW.

A low willow with glossy green leaves. Common in high altitudes.

Altitude: 8,500–11,500 ft. Distribution: Cather Springs; Middle Beaver Creek; Lake Moraine; Seven Lakes, Crystola; Ruxton Creek; French Creek; Cascade Cañon; Catamount Creek; Mt. Rosa; Pike's Peak; Bald Mountain.

Salix brachycarpa Nutt.

"Pike's Peak; Sheep Creek." (Rydberg).

Salix saximontana Rydb. DWARF WILLOW, NET-VEINED WILLOW.

This dwarf, prostrate willow is one of the three woody plants found above timber line.

Altitude: 9,000–14,000 ft. Distribution: Bald Mountain; North French Creek; Pike's Peak.

FAGACEÆ, OAK FAMILY.

Quercus Utahensis (A. D. C.) Rydb.

Distribution: Blair Athol; East of Cheyenne Mountain; Austin Bluffs.

Quercus Vreelandii Rydb.

Distribution: Cheyenne Mountain.

Quercus leptophylla Rydb.

Distribution: Fountain Creek; North Cheyenne Cañon.

Quercus Gunnisonii (Torr.) Rydb.

Distribution: Blair Athol; East of Cheyenne Mountain; North Cheyenne Cañon; Manitou; Austin Bluffs.

(Rydberg divides this species into *Q. nitescens, Q. novomexicana,* and *Q. Gunnisonii*).

Quercus Gambellii Nutt.

Distribution: Blair Athol; Cheyenne Mountain; Cheyenne Cañons; Manitou; Austin Bluffs.

Quercus Gambellii Fendleri (Liebm.) A. Nels.

Distribution: Blair Athol; Austin Bluffs.

BETULACEÆ, BIRCH FAMILY.

Betula fontinalis Sarg. ROCKY MOUNTAIN BIRCH.

A large shrub or tree sometimes 30 ft. high growing in clumps. The bark is a smooth brown, marked with grayish transverse lenticles. Very common along streams in cañons.

Altitude: 6,400–9,000 ft. Distribution: Cheyenne Cañons; Sutherland Cañon; Cheyenne Mountain; Cheyenne Creek; Buffalo Cañon; Ruxton Creek; Crystola; Manitou; French Creek; Cascade Cañon; Cather Springs; Rock Creek; Fountain Creek; Crystal Park; Mt. Rosa.

Betula glandulosa Michx. MOUNTAIN BOG BIRCH.

A low bush with rough, glandular, brown bark. Common in alpine bogs.

Altitude: 8,600–11,000 ft. Distribution: Clyde; Seven Lakes; Lake Moraine; Mountain View; French Creek; Cascade Cañon; Bald Mountain; Catamount Creek.

Alnus tenuifolia Nutt. PAPER-LEAF ALDER.

A tree or tall shrub usually with several trunks in a group. Along streams.

Altitude: 6,000–8,800 ft. Distribution: Ute Pass; Crystola; Manitou; Monument Creek; Fountain Creek.

Corylus rostrata Ait. BEAKED HAZEL-NUT.

A shrub growing in thickets along streams. The bracts project beyond the nut in a long, bristly beak.

Altitude: 6,400–8,000 ft. Distribution: North Cheyenne Cañon; Sutherland Cañon.

POLYGONACEÆ, BUCK-WHEAT FAMILY.

Eriogonum effusum Nutt.

A low plant with woody base and much branched, ascending inflorescence. Flowers small. Common on mesas and plains.

Altitude: 5,300–8,000 ft. Distribution: Mesa; Austin Bluffs; Plains.

Eriogonum microthecum Nutt.

"Colorado City." (Rydberg).

CHENOPODIACEÆ, GOOSE-FOOT FAMILY.

Atriplex canescens James. SHAD-SCALE, BUSHY ATRIPLEX.

A grayish green shrub with narrow leaves. The seeds are four-winged and crowded on the spike. Growing on mesas and alkaline draws.

Altitude: Up to 7,000 ft. Distribution: Mesa; Williams' Cañon; Garden of the Gods; Red Rock Cañon; Fountain Creek.

Eurotia lenata (Pursh) Moq. WINTER FAT, WINTER or WHITE SAGE.

A low, grayish wooly shrub of the plains and foothills. The seeds are cottony.

Altitude: Up to 8,000 ft. Distribution: Mesa; Williams' Cañon; Hills near Manitou; Plains.

RANUNCULACEÆ, CROWFOOT FAMILY.

Clematis ligusticifolia Nutt. WESTERN VIRGIN'S BOWER, WESTERN CLEMATIS.

A vine common along streams in the lower mountains and plains. Leaflets usually five. Flowers white. Fruit long-tailed and feathery.

Altitude: 5,300–6,800 ft. Distribution: Ute Pass; Williams' Cañon; Sutherland Cañon; Rock Creek; Cheyenne Cañons; Monument Creek; Cheyenne Creek; Fountain Creek; Manitou.

Clematis pseudoalpina (Kuntze) A. Nels. (*Atragene pseudoalpina* (Kuntze) Rydb.) PURPLE VIRGIN'S BOWER.

On hillsides in woods. Secondary leaflets toothed.

Altitude: 7,000–10,000 ft. Distribution: Pike's Peak; Cheyenne Mountain; Cascade Cañon; Mt. Rosa.

Clematis pseudoalpina tenuiloba (Gray) A. Nels. (*Atragene tenuiloba* (A. Gray) Britton). VIRGIN'S BOWER.

In mountain woods. Secondary leaflets divided to near the base. Flowers with four large purple sepals.

Altitude: 7,000–10,000 ft. Distribution: Williams' Cañon; Cheyenne Cañons; Sutherland Cañon; Clyde; Buffalo Cañon; Ruxton Creek; Crystola; Cascade Cañon; Cameron's Cone; Rock Creek; Crystal Park; Mt. Rosa; Bald Mountain.

HYDRANGEACEÆ, HYDRANGEA FAMILY.

Jamesia Americana T. & G. (*Edwinia Americana* (T. & G.) Heller). WAX FLOWER.

A much branched shrub, from 2 to 5 feet high, growing in cañons. It is often seen growing from crevices of steep rock cliffs. It has a white, waxy, fragrant flower.

Altitude: 6,400–10,500 ft. Distribution: Mt. Rosa; Crystal Park; Clyde; Cheyenne Cañons; Cameron's Cone; French Creek; Cather Springs; Williams' Cañon; Sutherland Cañon; Cheyenne Mountain; Buffalo Cañon; Bald Mountain; Pike's Peak; Manitou.

GROSSULARIACEÆ, GOOSEBERRY FAMILY.

Ribes saxosum Hook. (*R. purpusi* Koehne.) GOOSEBERRY.

A shrub with larger leaves than R. leptanthum. Greenish white flowers.

Altitude: 6,200–10,500 ft. Distribution: Williams' Cañon; Cheyenne Cañons; Sutherland Cañon; Ute Pass; Middle Beaver Creek; Blair Athol; Cameron's Cone; Cather Springs; Red Rock Cañon.

Ribes leptanthum A. Gray. GOOSEBERRY.

A branched, rigid bush with roundish, cleft leaves and large spines. Growing in cañons and foothills.

Altitude: 6,200–8,400 ft. Distribution: Ute Pass; Williams' Cañon; Cheyenne Cañons; Hills near Manitou; Rock Creek; Fountain Creek.

Ribes lentum (Jones) Coville and Rose. GOOSEBERRY.

A low, spiny shrub. The racemes bear several reddish flowers. The fruit is red and covered with gland tipped bristles. More common in higher altitudes.

Altitude: 7,800–10,500 ft. Distribution: Buffalo Cañon; North Cheyenne Cañon; Middle Beaver Creek; Lake Moraine; Seven Lakes; Ruxton Creek; French Creek; Rock Creek; Crystal Park; Mt. Rosa; Bald Mountain; Pike's Peak.

Ribes cereum Dougl. SQUAW CURRANT.

(Rydberg has divided this into two species: *R. pumilum* Nutt. and *R. inebrians* Lindl.)

An unarmed shrub growing in dry, exposed places on mesas, foothills and mountains. The leaves and flowers are glandular. The racemes of white or pinkish flowers are drooping. Fruit is red and insipid.

Altitude: 6,000–10,000 ft. Distribution: Mesa; Cheyenne Cañons; Rock Creek; Clyde; Crystal Park; Williams' Cañon.

Ribes longifolium Nutt. FLOWERING OR GOLDEN CURRANT.

A shrub with yellow, tubular flowers of spicy fragrance. Common along streams of the foothills and plains.

Altitude: 5,300–6,500 ft. Distribution: Manitou; Williams' Cañon; Cheyenne Cañons; Ute Pass; Cheyenne Creek; Fountain Creek; Monument Creek.

ROSACEÆ, ROSE FAMILY.

Physocarpus monogynus (Torr.) A. Nels. (*Opulaster monogynus* (Torr.) Kuntze). COLORADO NINEBARK.

A low shrub, with clusters of white flowers, common on rocky mountain sides and in gulches, or sometimes along streams. Carpels two.

Altitude: 6,500–9,000 ft. Distribution: Mt. Rosa; Cascade Cañon; Cather Springs; Crystal Park; Williams' Cañon; Cheyenne Cañons; Sutherland Cañon; Clyde; Ruxton Creek; Woodland Park; Cameron's Cone; Cutler Mountain; Cheyenne Mountain; French Creek; Pike's Peak.

Physocarpus intermedius (Rydb.) A. Nels. (*Opulaster intermedius* Rydb.) WYOMING NINEBARK. Known locally as Rocky Mountain Snow-ball.

A beautiful shrub, often five or six feet tall, common near streams in cañons. More showy flowers than the preceding. Carpels from 3 to 5.

Altitude: 6,200–7,000 ft. Distribution: Cheyenne Cañons; Sutherland Cañon; Cheyenne Creek; Stratton Park; Rock Creek; Ruxton Creek.

Physocarpus Ramaleyi A. Nels. (*Opulaster Ramaleyi* A. Nels.) NINEBARK.

A shrub, from 4 to 6 ft tall, growing in cañons. Not common here. The bracts are foliaceous and persistent. Carpels two.

Altitude: Up to 8,500 ft. Distribution: South Cheyenne Cañon; Blair Athol.

Cercocarpus parvifolius Nutt. MOUNTAIN MAHOGANY, MOUNTAIN HOLLY.

A shrub, from 2 to 7 ft. high, growing on dry rocky slopes of mesas, foothills, and lower mountains. Often forming dense clumps. The seeds have feathery, curled tails two or three inches long.

Altitude: 6,000–9,400 ft. Distribution: Rock Creek; Cutler Mountain; Pike's Peak; Black Cañon; Ute Pass; Cheyenne Cañons; Sutherland Cañon; Stratton Park; Austin Bluffs; Mesa; Hills near Manitou; Crystola; Woodland Park; Glen Eyrie.

Dasiphora fruticosa (L.) Rydb. SHRUBBY CINQUEFOIL.

A shrub with grayish, pinnate leaves and a bright yellow flower. In mountain meadows and along streams. Most common at about 10,000 feet and one of the three woody plants above timber line.

Altitude: 6,500–12,400 ft. Distribution: Seven Lakes; Cheyenne Cañons; Buffalo Cañon; Clyde; Lake Moraine; Windy Point; Ruxton Creek; Mt. Rosa; Cameron's Cone; French Creek; Cascade Cañon; Middle Beaver Creek; Crystola; Cather Springs; Bald Mountain.

Rubus strigosus Michx. RED RASPBERRY.

The red raspberry is common on mountain sides. It is one of the early invaders of the gravelslide.

Altitude: 6,000–10,000 ft. Distribution: Clyde; Williams' Cañon; Cheyenne Cañons; Sutherland Cañon; Cheyenne Mountain; Buffalo Cañon; Lake Moraine; Ruxton Creek; Crystola; French Creek; Cascade Cañon; Crystal Park; Mt. Rosa; Pike's Peak; Bald Mountain.

Bosseckia delicicsa (James) A. Nels. (*Rubus deliciosus* James or *Oreobatus deliciosus* (James) Rydb.) ROCKY MOUNTAIN THIMBLE BERRY.

A handsome shrub, with drooping stems, growing along the streams and on the slopes of our lower mountains. Its white flower is an inch or two broad.

Altitude: 6,000–10,000 ft. Distribution: Williams' Cañon; Cheyenne Cañons; Sutherland Cañon; Cheyenne Mountain; Cheyenne Creek; Buffalo Cañon; Ruxton Creek; Glen Eyrie; Rock Creek; Ute Pass; Manitou; Cascade Cañon; Crystal Park; Mt. Rosa; Pike's Peak; Bald Mountain; Bear Creek Cañon.

Holodiscus dumosa (Nutt.) Heller. MEADOW SWEET.

An attractive shrub on the slopes of the foothills and lower mountains. It has large clusters of feathery flowers at the ends of the branches. Leaves with double teeth.

Altitude: 6,200–9,000 ft. Distribution: Ute Pass; Williams' Cañon; Cheyenne Cañons; Mt. Rosa; Cheyenne Mountain; Buffalo Cañon; Hills near Manitou; Cascade Cañon; Cather Springs; Green Mountain Falls; Rock Creek.

Holodiscus australis Heller. MEADOW SWEET.

Quite similar to the preceding except that the leaves have simple ovate teeth.

Altitude: Up to 9,000 ft. Distribution: Clyde; Cather Springs; Ruxton Creek; Cascade Cañon; St. Peter's Dome.

Dryas octopetala L. WHITE MOUNTAIN AVENS.

A dwarf, prostrate shrub with simple toothed leaves and large, solitary, white flowers. It is one of the three woody plants occurring above timber line.

Altitude: 11,500–14,000 ft. Distribution: Bald Mountain; Pike's Peak; North French Creek above Glen Cove.

Rosa Fendleri Crepin.

Distribution: Williams' Cañon; Buffalo Cañon; Cheyenne Creek; Blair Athol; Sutherland Cañon; Rock Creek.

Rosa Arkansana Porter.

(Rydberg divides this into *R. arkansana* and *R. pratincola*).

Distribution: Mesa; Colorado Springs; Plains; North Cheyenne Cañon.

Rosa Sayi Schweinitz.

(Rydberg divides this into *R. Sayi* and *R. Engelmannii*).

Distribution: North Cheyenne Cañon; Sutherland Cañon; Ruxton Creek; Manitou.

Rosa MacDougalii Holz. (*Rosa Underwoodii* Rydb.)

Distribution: Williams' Cañon; South Cheyenne Cañon.

Rosa Woodsii Lindl.

(Rydberg divides this into *R. aciculata* and *R. Macounii*).

Distribution: Fountain Creek; Ruxton Creek; Cheyenne Creek; Sutherland Cañon; Monument Creek; North Cheyenne Cañon.

POMACEÆ, APPLE FAMILY.

Sorbus scopulina Greene. AMERICAN OR WESTERN MOUNTAIN ASH.

An erect shrub with clusters of white flowers, which are followed by red berries. Leaflets from 4 to 6 pairs. Not abundant.

Altitude: 6,700–8,700 ft. Distribution: North Cheyenne Cañon; Bear Creek Cañon; Buffalo Cañon.

Cratægus coloradensis A. Nels. THORN APPLE.

A shrub found in gulches of the foothills. Often associated with oak thickets. The thorn is from 1¼ to 2 inches long. Fruit usually with three nutlets.

Distribution: East side of Cheyenne Mountain.

Cratægus cerronis A. Nels. THORN APPLE OR HAWTHORN.

A shrub or small tree with red fruit, usually containing five nutlets. Thorn from ¾ to 1 inch long.

Distribution: East side of Cheyenne Mountain.

DRUPACEÆ, PLUM FAMILY.

Prunus melanocarpa (A. Nels.) Rydb. CHOKE CHERRY.

A shrub or small tree growing abundantly along streams and on hillsides. The white flowers are in long racemes. Fruit is black.

Altitude: 5,300–9,000 ft. Distribution: Williams' Cañon; Cheyenne Cañons; Sutherland Cañon; Cheyenne Mountain; Stratton Park; Buffalo Cañon; Clyde; Ute Pass; Austin Bluffs; Cascade Cañon; Fountain Creek; Rock Cañon; Crystal Park; Monument Creek.

Prunus pennsylvanica L. WILD RED CHERRY.

A small tree growing in cañons and on hillsides. The fruit is light red and small.

Altitude: 6,200–8,600 ft. Distribution: Ruxton Creek; North Cheyenne Cañon; Sutherland Cañon; Cheyenne Mountain; Buffalo Cañon; Cather Springs; Pike's Peak.

Prunus americana Marsh. COMMON WILD PLUM.

Usually growing in thickets along streams on foothills and plains. Shrub thorny.

Altitude: 5,300–6,500 ft. Distribution: Bear Creek; Fountain Creek; East of Cheyenne Mountain; Cheyenne Creek.

PAPILIONACEÆ, PULSE FAMILY.

Amorpha fruticosa L. FALSE INDIGO.

A tall shrub with spikes of violet purple flowers. Along streams.

Altitude: 6,000–6,400 ft. Distribution: Rock Creek; Monument Creek; Cheyenne Creek.

Robinia neo-mexicana A. Gray. PINK LOCUST.

A small tree growing along Fountain Creek in and near Manitou. Flowers pink, in dense hanging racemes. It is doubtful whether this is an indigenous species.

Distribution: Manitou; Touzalin Ranch.

ANACARDIACEÆ, SUMAC FAMILY.

Rhus Rydbergii Small. POISON IVY, POISON OAK.

A low plant common among bushes in the cañons. The three-parted leaves turn red in the autumn, the greenish white fruit remains on during the winter.

Altitude: 5,300–7,500 ft. Distribution: Ute Pass; Williams' Cañon; Cheyenne Cañons; Ruxton Creek; Cheyenne Creek; Fountain Creek; Blair Athol.

Rhus cismontana Greene. (*Schmaltzia glabra* (L.) Small). SMOOTH or SCARLET SUMAC.

A shrub with pinnate leaves of from 9 to 31 leaflets. Flowers in terminal clusters. The fruit is acid to taste and of a scarlet color.

Altitude: 6,000–7,000 ft. Distribution: Rock Creek; Sutherland Cañon; Cheyenne Mountain; Stratton Park; North Cheyenne Cañon.

Rhus trilobata Nutt. (*Schmaltzia trilobata* (Nutt.) Small). ILL-SCENTED SUMAC, SKUNK BUSH.

A low ill-scented shrub common on mesas and dry foothills. The flowers are a yellowish green and followed by bunches of red berries.

Altitude: 5,300–7,000 ft. Distribution: Mesas; Williams' Cañon; Sutherland Cañon; Cheyenne Cañons; Ute Pass; Blair Athol; Manitou; Austin Bluffs; Hills near Manitou; Rock Creek; Red Rock Cañon; Fountain Creek.

ACERACEÆ, MAPLE FAMILY.

Acer Negundo L. (*Rulac Negundo* (L.) Hitchc.) BOX ELDER.

A tree not widely distributed. It appears to have been introduced.

Distribution: Touzalin Ranch; Fountain Creek near Manitou.

Acer glabrum Torr. ROCKY MOUNTAIN MAPLE.

A tall shrub, usually growing in clumps, rarely a tree, common along the streams and sides of cañons. It may be recognized by its bright, red winter buds.

Altitude: 6,400–9,000 ft. Distribution: Williams' Cañon; Cheyenne Cañons; Sutherland Cañon; Buffalo Cañon; Blair Athol; Ute Pass; Crystola; Cascade Cañon; Cather Springs; Mt. Rosa; Middle Beaver Creek; Bald Mountain; Ruxton Creek.

Acer grandidentatum Nutt.

Not found by the writer.

Distribution: "Pike's Peak" (Rydberg).

RHAMNACEÆ, BUCKTHORN FAMILY.

Ceanothus mollissimus Torr. (*C. pubescens* (T. & G.) Rydb). NEW JERSEY TEA.

A low branched shrub, with terminal umbels of white flowers, common in oak thickets. In the lower mountains and cañons.

Altitude: 6,000–6,700 ft. Distribution: Stratton Park; Cheyenne Mountain; North Cheyenne Cañon; Blair Athol; East of Cheyenne Mountain.

VITACEÆ, VINE FAMILY.

Vitis vulpina L. RIVERBANK GRAPE.

A vine climbing by tendrils. Along streams in cañons.

Altitude: 7,000 ft. Distribution: Ute Pass; Manitou; North Cheyenne Cañon.

Parthenocissus vitacea Hitchc. VIRGINIA CREEPER.

A vine having tendrils without disks. Leaflets five. Often mistaken for poison ivy which has only three leaflets.

Altitude: Up to 6,600 ft. Distribution: Ute Pass; Williams' Cañon; Cheyenne Cañons; Hills near Manitou; Rock Creek; Manitou.

ONAGRACEÆ, EVENING PRIMROSE FAMILY.

Meriolix serrulata (Nutt.) Walp. TOOTH-LEAVED EVENING PRIMROSE.

A low plant with woody base. Flowers yellow. Growing on the plains.

Distribution: Plains; Austin Bluffs; Fountain Creek.

CORNACEÆ, DOGWOOD FAMILY.

Cornus stolinifera Michx. DOGWOOD.

A medium sized, branched shrub, with reddish-purple branches, and clusters of white flowers, which are followed by white berries. Growing in wooded cañon bottoms.

Altitude: 5,300–9,000 ft. Distribution: Rock Creek; Williams' Cañon; South Cheyenne Cañon; Sutherland Cañon; Crystola; Manitou; Lower Fountain Creek; Monument Creek; Ruxton Creek.

Cornus Baileyi Coult. & Evans. (*Svida interior* Rydb.)

Similar to the preceding.

Distribution: Monument Creek; Fountain Creek.

ERICACEÆ. HEATH FAMILY.

Arctostaphylos uva-ursi (L.) Spreng. KINNIKINIC, BEAR-BERRY.

A trailing, prostrate, evergreen plant. The fruit is a red berry. On mountain slopes and in woods.

Altitude: 6,000–10,200 ft. Distribution: Pike's Peak; Bald Mountain; Williams' Cañon; Cheyenne Cañons; Sutherland Cañon; Buffalo Cañon; Ruxton Cañon; Cameron's Cone; Blair Athol; French Creek; Cascade Cañon; Mt. Rosa; Crystal Park.

VACCINIACEÆ, HUCKLEBERRY FAMILY.

Vaccinium cæspitosum Michx. DWARF BILBERRY, BLUE-BERRY.

A low branched shrub with round stem; solitary flowers in the axils of the small leaves. The berry is blue with a bloom. Found growing in moist woods in the higher mountains.

Altitude: 8,600 ft. Distribution: South Cheyenne Cañon.

Vaccinium oreophilum Rydb. BILBERRY or RED BLUE-BERRY.

The stem is angled and the fruit purplish black. Growing in woods.

Altitude: 8,400–10,500 ft. Distribution: Lake Moraine; Cascade Cañon; Mt. Rosa; Bear Creek.

CAPRIFOLIACEÆ, HONEYSUCKLE FAMILY.

Sambucus microbotrys Rydb. RED-BERRIED ELDER.

A low shrub with oblong bunches of white flowers and pinnate leaves. The shrub grows in moist soils.

Altitude: 6,700–11,000 ft. Distribution: North Cheyenne Cañon; Sutherland Cañon; Clyde; Ruxton Creek; Crystola; Cameron's Cone; French Creek; Pike's Peak; Middle Beaver Creek; Bald Mountain.

Lonicera involucrata (Rich) Banks. (*Distegia involucrata* (Rich) Rydb.) INVOLUCRED FLY-HONEYSUCKLE.

A shrub growing in moist cañons near the streams. The flower is yellowish, irregular, and one-half or more inches long, and has two bracts, which later surround the purplish twin berries.

Altitude: 7,200–9,200 ft. Distribution: Crystola; Cascade Cañon; French Creek.

Symphoricarpos occidentalis Hook. WOLF-BERRY.

A shrub with opposite, thick leaves and solitary, pink flowers. The fruit is a greenish white berry. Very common along streams in the foothills.

Altitude: 5,300–7,200 ft. Distribution: Williams' Cañon; Cheyenne Cañons; Cheyenne Mountain; Blair Athol; Ute Pass; Austin Bluffs; Rock Creek; Monument Creek; Sutherland Cañon; Fountain Creek.

Symphoricarpos orbiculatus Mœnch. (*S. Symphoricarpos* (L.) Mac M.) CORAL-BERRY, INDIAN CURRANT.

A low shrub with opposite leaves and axillary flowers. In fruit the stem is filled with crowded clusters of red berries.

Distribution: Manitou; Cheyenne Creek.

Symphoricarpos racemosus pauciflorus Robbins. (*S. pauciflorus* (Robbins) Britton). LOW SNOW-BERRY.

A very common low shrub, in open woods, on mountain slopes. The leaves are thin. The solitary, pink flowers are usually in the axils of the upper leaves. The fruit is a white berry which persists during the winter.

Altitude: 6,600–9,000 ft. Distribution: Mt. Rosa; Cheyenne Cañons; Williams' Cañon; Cheyenne Mountain; Buffalo Cañon; Cameron's Cone; Rock Creek; Cascade Cañon; Mt. Rosa; Pike's Peak.

Viburnum pauciflorum Pylaie. FEW-FLOWERED CRANBERRY, HIGH-BUSH CRANBERRY.

A branched shrub, from 2 to 5 ft. high, with palmately veined, three-lobed leaves, and clusters of small white flowers. Found growing in moist cañons.

Altitude: 6,900–9,000 ft. Distribution: Bear Creek; Buffalo Cañon; Cheyenne Cañons; Crystola; Sutherland Cañon.

Linnæa americana Forbes. AMERICAN TWIN-FLOWER.

A trailing, evergreen plant growing on moist shaded north slopes. The nodding, pink flowers grow in pairs on long, slender peduncles.

Altitude: 8,400–9,500 ft. Distribution: French Creek, South Cheyenne Cañon; Crystola.

LORANTHACEÆ, MISTLETOE FAMILY.

Arceuthobium cryptopodum Engelm. (*Razoumofskya cryptopodum* (Engelm.) Coville).

A parasite on yellow pine.

Distribution: Ute Pass; Cheyenne Cañons; Blair Athol; Crystal Park; Woodland Park.

Arceuthobium Douglasii Engelm. (*Razoumofskya Douglasii* (Engelm.) Kuntze).

Parasitic on Douglas spruce.

Distribution: North Cheyenne Cañon; Williams' Cañon.

Arceuthobium cyanocarpa A. Nels. (*Razoumofskya cyanocarpa* A. Nels.)

Parasitic on white pine.

Distribution: "Cheyenne Mountain." (Rydberg).

COMPOSITÆ, COMPOSITE FAMILY.

Artemesia frigida Willd. PASTURE SAGE-BRUSH, WORMWOOD SAGE.

Common on plains and in rocky soils.

Distribution: Mesa; Williams' Cañon; Blair Athol; Clyde; Ute Pass; Crystola, Austin Bluffs; Plains; Cascade.

Gutierrezia linearis Rydb.
Distribution: Red Rock Cañon.

Gutierrezia Sarothræ (Pursh.) B. & R. GUTIERREZIA.
Distribution: Mesa; Ute Pass; Austin Bluffs; Plains; Fountain Creek; Hills near Manitou.

Gutierrezia diversifolia Greene.
Distribution: "Manitou." (Rydberg).

Gutierrezia juncea Greene.
Distribution: "Garden of the Gods" (Rydberg).

Gutierrezia scoparia Rydb.
Distribution: "Colorado Springs; Manitou." (Rydberg).

Chrysothamnus graveolens (Nutt.) Greene. STRONG-SCENTED RABBIT-BUSH.
Distribution: Ute Pass; Mesa; Fountain Creek.

Chrysothamnus Howardii (Parry) Greene. HOWARD'S RABBIT-BUSH.
Distribution: Ute Pass; Fountain Creek.

Chrysothamnus virens Greene.
Distribution: "Pike's Peak" (Rydberg).

Chrysothamnus patens Rydb.
Distribution: "Manitou" (Rydberg).

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A History of the Arithmetical Methods of Approximation to the Roots of Numerical Equations of one Unknown Quantity . . . .

Florian Cajori.

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A HISTORY OF THE ARITHMETICAL METHODS OF APPROXIMATION TO THE ROOTS OF NUMERICAL EQUATIONS OF ONE UNKNOWN QUANTITY.

FLORIAN CAJORI.

INTRODUCTION.

During the Renaissance the algebraic solution of equations became a subject of profound study. The brilliant success of the Italians in finding algebraic solutions of cubic and quartic equations raised great hopes in the minds of mathematicians everywhere that the algebraic solution of general equations of still higher degrees might be discovered. But all hopes were shattered when Abel proved rigorously that such a solution was impossible. This impossibility, combined with the difficulty arising in the deduction of numerical results in the so-called "irreducible case" of cubic and quartic equations, has forced mathematicians to search for other than algebraic methods of solving numerical equations.

The algebraic solution of equations belongs to what has been called "precise mathematics," as distinguished from "approximate mathematics," to which our subject of root-approximation belongs. Precise mathematics demands that the equation $f(x)=0$ be satisfied absolutely; approximate mathematics looks upon $f(x)=0$ simply as an abbreviation for the inequality $|f(x)|<\epsilon$, where ϵ is the degree of approximation demanded by the practical problem at hand. The physicist, chemist and engineer use approximate mathematics almost exclusively. To them the solution of numerical equations by approximation is a problem of vital importance.

In this monograph we shall limit ourselves to the study of the development of *arithmetical* methods of approximation to the roots of equations of one unknown quantity; in a later publication we hope to be able to trace the history of solutions

which have been effected by trigonometric and elliptic functions, by mechanical methods and by purely geometric devices.

It is worthy of notice that the solution of numerical equations received the life-long attention of two mathematicians of the highest rank—Lagrange and Fourier. Both made this a subject of their earliest researches, both showed marked partiality for it in their old age. This fact is sufficient to indicate the importance of the problem. As Arago very aptly remarks, "A scientific subject does not occupy so much space in the life of a man of science of the first rank without being important and difficult. The subject of algebraic analysis above mentioned . . . is not an exception to this rule. It offers itself in a great number of applications of calculation to the movements of the heavenly bodies, or to the physics of terrestrial bodies, and in general in problems which lead to equations of a high degree. As soon as he wishes to quit the domain of abstract relations, the calculator has occasion to employ the roots of these equations; thus the art of discovering them by the aid of an uniform method, either exactly or by approximation, did not fail at an early period to excite the attention of geometers."[1]

PART I. BEFORE VIETA.

Approximation to the principal real roots of pure equations not usually exceeding the fourth degree. Sporadic attempts to approximate to the roots of affected equations.

The different devices for the extraction of the square root, the cube root and higher roots of numbers yield approximate solutions of pure equations of the form $x^n - a = 0$ and, for that reason, come within the sphere of this monograph. It is probable that root-extraction was an art practiced by

[1] F. ARAGO, *Biographies of Distinguished Scientific Men.* First Series Boston, 1859, p. 381 (Joseph Fourier).

scholars in very early ages. If M. Cantor's interpretation of the Babylonian tables of Senkereh, as given in the third edition of the first volume of his great history,[1] is correct, then these are not tables of squares and cubes, as formerly supposed, but tables of square roots and cube roots, and the Babylonians had some familiarity with root-extraction 4,000 years ago. It remains for Assyriologists to determine beyond doubt the proper interpretation of these tables and to ascertain how the operations were performed.

That the Greeks had clearly grasped the root-concept is a matter of common knowledge. The isosceles right triangle led the Pythagoreans to the quadratic irrational $\sqrt{2}$. Later the problem of the duplication of the cube brought the Greeks to the cubic irrational $\sqrt[3]{2}$. Still later we find in Archimedes' work on the *Measurement of the Circle* numerous close approximations to square roots, but the method by which the results were obtained is nowhere explained. For lack of space we shall pass by the numerous interesting conjectures which have been made as to the process followed by Archimedes, except to mention that there is reason to believe that he found his approximate square roots by the formula of Heron, $\sqrt{a^2 \pm b} = a \pm \frac{b}{2a}$.[2] Heron also gives approximate values of cube roots of numbers, and many conjectures have been made on Heron's probable method of cube root extraction.[3]

Some centuries later, Theon of Alexandria explains the $\sqrt{4500^\circ} = 67^\circ 4' 55''$ by a method which agrees with that of the present time, except that he uses sexagesimal instead of decimal fractions. Led by geometric considerations, Theon

[1] *Vorlesungen ueber Geschichte der Mathematik* Bd. I, 3rd Ed., Leipzig, 1907. See also M. Cantor's article, "Babylonische Quadratwurzeln und Kubikwurzeln' in *Zeitsch. f. Assyriologie*, Bd. XXI, 1907–1908, pp. 110–115.

[2] Cantor *Vorl. ueber Gesch. d. math.* Bd. I, 3rd Ed., Leipzig, 1907, p. 372. *Bibliotheca Mathematica* (3) 7, 1907, p. 99: (3) 8, 1908, p. 411: (3) 9, p. 238.)

[3] Cantor *op. cit.* Vol. I., 3rd Ed., p. 374; *Bibliotheca Mathematica* (3) 8, pp. 412, 413.)

finds the largest square in 4500° to be $4489=67^2$; dividing the difference of 11° or 660′ by 2×67, he gets 4′; he then subtracts $2\times4'\times67$ or 536′ from 660′, and obtains 124′ or 7440″; next $7440''-4'\times4'=7424''$; dividing 7424″ by 134°8′ he gets finally 55″ as an approximation.[1]

By a strange turn of events it was not the Greek writers on root extraction, but the astronomers on the far-off banks of the Ganges, who influenced the more modern European writers on algebra. In Bhaskara's book, called *Lilavati* ("the beautiful"), written in the year 1150, one finds evidence that the art of computation had reached a high degree of perfection among the Hindus.[2] Bhaskara was familiar with the relations $(a+b)^2=a^2+2ab+b^2$, $(a+b)^3=a^3+3a^2b+3ab^2+b^3$ and he used them in the extraction of roots. His process was much like that of the present day, except that he did not have decimal fractions. But root extraction must have been practiced much earlier among the Hindus, for Aryabhatta, the earliest great Hindu astronomer, speaks of dividing the digits into groups of two and three in finding square and cube roots.[3] This division is also made by Planudes, who gives $\sqrt{18}=4\frac{1}{4}$ as his first example under roots and gives the following rule which is found also in the *liber abaci* of the Italian Leonardo of Pisa, published in 1202. Take the root of the next smaller perfect square, subtract its square from the given number and divide the remainder

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[1]Fabricius, *Bibliotheca Graeca* (ed. Harless) IX, 176, 178–179: see also M. Cantor, *Vorles ue. Geschichte d. Mathematik* 1 er Bd., Leipzig, 1894, p. 461.

[2]The mathematical chapters of Bhaskara's work were translated into English by H. T. Colebrooke in a publication, entitled, *Algebra with arithmetic and mensuration, from the Sanscrit of Brahmegupta and Bhaskara*, London, 1817. This translation gives only meagre information on the practical execution of computations. On this point greater detail is given in the English translation of the *Lilavati* made by Taylor (Bombay, 1816) and in C. I. Gerhardt's *Rechenbuch des Maximus Planudes*, Halle, 1865. The present knowledge of Hindu methods of computation is derived partly from the Hindu works, but mainly from the arithmetic of Planudes, who lived in the first half of the fourteenth century, and who avowedly used Hindu sources.

[3]L. Rodet, *Leccns de calcul d'Aryabhata*, p. 9, 18, etc.

by twice the divisor. Planudes proceeds to roots of larger numbers. He finds for the square root of 1690196789 the value $41112\frac{245}{82224}$. Finally he suggests some modifications of the process which from the modern point of view are far from being improvements.[1] Planudes begins by multiplying the number by 3600. At the close he divides the square root by 60. This method, which Planudes claims for himself, is found also in an earlier work by John of Seville, an Arabic author to be mentioned later. The multiplication by 3600, according to the sexagesimal system, is in principle the same as the process of adding zeros, according to the decimal system, practiced as early as 850 by the Arabic authors, known as the Three Brothers.[2]

Hindu methods were transmitted to the Arabs and by them to the Europeans.

John of Seville wrote a *liber alghoarismi*, compiled by him from Arabic authors about 1140 A. D., in which $2n$ zeros are added to a number of which the square root is sought, and the square root of this is taken as the numerator of a fraction whose denominator is 1, followed by n zeros. Probably through John of Seville, this mode of procedure became known to the European mathematicians of the Renaissance, like Ciruelo, Grammateus, Cardan and others. We pass by certain special formulæ sometimes used by the Arabs in finding the square and cube roots of numbers, but desire to state that to the Arabs belongs the credit of extending the root-concept to higher orders. Omar Alchaijami, an astronomer at Bagdad (died 1123), declares that he taught how to find the sides of a square-square, a square-cube, a cube-cube, and so on,[3] and that he gave arithmetical proofs of his processes, based on the arithmetical chapters in Euclid's *Elements*. The last remark appears to indicate a familiarity with the binomial series for positive integral exponents.

[1] C. I. Gerhardt, *op. cit.* p. X; Cantor, *op. cit.* I, 3rd Ed., p. 512: *Bibliotheca Mathematica* (3) 9, pp. 140, 141.

[2] *Bibliotheca Mathematica* 4 (3), 1903, p. 217.

[3] *L'Algebre d'Omar Alkhayyami*, ed. Woepke, Paris, 1851, p. 13.

In the solution of equations of the first degree several Arabic authors use the "rule of two false positions." The rule of a single "false position" is one of the very oldest in mathematics. It is found in the Ahmes papyrus; it is used by Diophantus, by the Hindus and Arabs in the solution of problems. The rule of "two false positions" is attributed to the Hindus. It is used in the solution of equations of the first degree by *Abraham ben Esra* (1130), *Ibn Albanna* (1222), *Alkalzadi* (died 1486), and *Beha Eddin* (1547-1622).[1] If $ax+b=0$, let m and n be any two numbers ("two false positions"), let also $am+b=M$, $an+b=N$, then $x=(nM-mN)\div(M-N)$.

Of interest is the approximate solution of the cubic $x^3+Q=Px$, which grew out of the computation of $x=\sin 1°$. The method is shown only in this one numerical example. It is given by Miram Tschelebi in 1498, in his annotations of certain Arabic astronomic tables.[2] The solution is attributed to Atabedkin Dschamschid. It is the only known approximate arithmetical solution of an affected equation due to Arabic writers. We shall see that on the European continent such solutions were published at a somewhat earlier date. In the above cubic, P and Q are both assumed positive, and P larger than Q. Consequently x is small. Hankel illustrates the process of solution by an example of his own. In general terms the process is as follows: Write $x=(Q+x^3)\div P$. If $Q\div P=a+R\div P$, then a is the first approximation, x being small. We have $Q=aP+R$, and consequently $x=a+(R+a^3)\div P=a+b+S\div P$, say. Then $a+b$ is the second approximation. We have $R=bP+S-a^3$ and $Q=(a+b)P+S-a^3$. Hence $x=a+b+(S-a^3+(a+b)^3)\div P=a+b+c+T\div P$, say. Here $a+b+c$ is the third approximation, and so on.

[1] L. Matthiessen, *Grundz. d. Antiken u. modernen Algebra*, Leipzig, 1878, p. 275.

[2] *Journal asiatique*, 1853, série 5, T. II, p. 347. See also Cantor *op. cit.*, Vol. I, 1894, p. 736; H. Hankel, *Geschichte d. Math. im Alterthum u. Mittelalter*, Leipzig, 1874, pp. 290–292.

In the practical application of this process are involved the successive divisions by P and the cubing of a, $a+b$, $a+b+c$, etc. The amount of computation is considerable. If it be remembered, moreover, that the process was limited to cases in which P and Q are positive, and P comparatively large, it must be admitted that it has no great value as a method of solving cubic equations by approximation. As the Arabs operated with positive numbers only, a negative P and Q would have meant the solution of $x^3+Px=Q$, to them an entirely different problem. The high praise given this method by Hankel[1] is not warranted by the facts. Hankel says that "this beautiful method of solving numerical equations stands second to none of the methods of approximation invented in the Occident since the time of Vieta, in fineness and elegance." It must be admitted, however, that it answered well the immediate purpose of computing $x=\sin 1°$.

Nearly 300 years before the publication of the above approximation in 1498, the genial Italian mathematician, Leonardo of Pisa, had solved the cubic $x^3+2x^2+10x=20$ to a high degree of approximation, giving as the answer $x=1°22'\ 7''42'''33^{IV}4^{V}40^{VI}$. How he obtained this extraordinary result he does not explain, and we are left in ignorance of the nature of its solution.[2]

The earliest known process of approaching to a root of an affected numerical equation was invented by Nicolas Chuquet, who, in 1484 at Lyons, wrote a work of high rank, entitled *Le Triparty en la science des nombres.* It was never printed until 1880.[3] Chuquet takes $\frac{a+b}{c+d}$ as an intermediate value[4] of $\frac{a}{c}$ and $\frac{b}{d}$, and proceeds to apply it to the solution of

[1] H. Hankel, *op. cit.* p. 292.

[2] Genocchi in *Annali di scienze matematiche e fisiche* (Tortolini) VI, pp. 165–168, conjectures that Leonardo's mode of approximation was the same as that used later by Cardan, but there is nothing to support this conjecture.

[3] Printed in the *Bulletino Boncompagni* T. XIII, 1880; see pp. 653–654.

[4] Cantor points out that Pappus gave in his *Mathematical Collections* Bk. VII, Lemma 8 (Ed. Hultsch II, 688 and 690), the same expression of an intermediate value used by Chuquet, but makes no application of it to the solution of equations.

$x^2+x=39\frac{1}{8}\frac{2}{4}$. The equation and its solution are expressed in words. Only the numbers are written in mathematical symbols. The exposition is what Nesselmann would have called "rhetorical." Chuquet finds $x=5$ too small and $x=6$ too large. The intermediate value is $5\frac{1}{2}$, which is too small. His intermediate value of 6 and $5\frac{1}{2}$ is $\frac{6+11}{1+2}$ or $5\frac{2}{3}$, which is still too small. The third intermediate value between $5\frac{2}{3}$ and 6 is $5\frac{3}{4}$, and is also too small. The fourth intermediate value is $5\frac{4}{5}$; the fifth gives the accurate result, $5\frac{7}{8}$. The method is very laborious, the rate of approximation is slow. Unlike most modes of approximation, it yields results, not in decimal, but in common fractions.

The earliest printed method of approximation to the roots of affected equations is that of *Hieronimo Cardano* (1501-1576) of Milan, who gave it in the *Ars magna* (1545) under the title *De regula aurea.*[1] Cardano's method applies to equations of any degree, but is shown by him only for cubics and quartics. Let all letters stand for positive numbers and let a and $a+1$ be integers, such that, in the equation $f(x)=k$, $f(a)=k-b$ and $f(a+1)=k+b^1$. Then x lies between these integers, and we may put $x=a+\theta$ and $x=a+1-\theta\varepsilon$, where θ and ε are proper fractions. Take

$$\theta=\frac{f(x)-f(a)}{f(a+1)-f(a)}=\frac{b}{b+b^1},$$

then $x=a+\theta$ is a second approximation.

If $f(a+\theta)=k-b''$, take

$$\varepsilon=\frac{f(a+1)-f(x)}{f(a+1)-f(a+\theta)}=\frac{b'}{b'+b''}$$

and we have a third approximation $x=a+1-(1-\theta)\varepsilon$. We get $f(a+1-\varepsilon+\theta\varepsilon)=k$ plus or minus a small number. The interval between which the root lies is thus narrowed down between $a+1-\varepsilon+\theta\varepsilon$ and either $a+\theta$ or $a+1$, as the case

[1]Cardano IV, 273-274; see also Cantor, Vol. II, 2nd Ed., 1900, p. 506.

may be. With these closer limits the above process is repeated until the required degree of precision is reached. At first Cardan assumed the coefficients in the given equation to be all positive, but later in his work he partly dropped this limitation. Strange to say, Cardan's *regula aurea* made no impression upon the mathematicians of his day, notwithstanding the fact that it was the earliest method applicable to equations of all degrees, though not applied by himself to equations higher than the fourth. That the method requires much computation hardly explains why Clavius, Stevin and Vieta did not refer to it. All pre-Newtonian methods were laborious.

In the procedure of Cardan we see an interesting application of the rule of "two false positions."

The method of two false positions had been applied to the extraction of square roots in the *Liber augmenti et diminuationis*[1] (12th century) and later in the *Arithmeticae practicae methodus facilis* (1558) of Rainer Gemma Frisius.[2] In the latter publication the square, cube, and fourth roots are found also by the rule of single position.[3]

In 1554 J. Peletier showed[4] that, if an equation $x^2=ax+b$ or $x^3=ax^2+b$, where a and b are positive integers, has a rational root, then this root (and in the second equation also its square), must be a factor of b. Along the same line was a suggestion of Raphael Bombelli who in his *Algebra*, published in Bologna in 1572, showed (page 180) how to look for positive integral roots of $4p^3-3cp=a$, where a and c were given positive integers.[5] He wrote $p^2+q=c$, $p^3-3pq=a$. Upon assuming q positive, he obtained $\sqrt[3]{a}<p<\sqrt{c}$, which made it easier to find p. If $a=2$, $c=5$, then p is seen to be 2. Some-

[1] Libri, *Histoire des sciences mathématiques en Italie* I. p. 305, 307, etc.: *Bibliotheca Mathematica* (3) 7, 1906–07, p. 89.

[2] Cantor, *op. cit.* Vol. 2, 2nd Ed., p. 412.

[3] *Bibliotheca Mathematica* (3) 7, 1906–'07, p. 89.

[4] *L'algebre de Jaques Peletier*, Lyon 1554, pp. 39–46. See Eneström in *Bibliotheca Mathematica* (3) 7, 1906–'07, p. 390.

[5] *Bibliotheca Mathematica* (3), 8, 1907–08, p. 87.

what similar considerations occurred in Raimarus Ursus's *Arithmetica Analytica* (1601, Frankfurt an der Oder), who describes a process ascribed by him to Johannes Junge of Schweidnitz in Prussia. The process, said to have been first thought out by Junge in 1577, was crude and uncertain, consisting originally in trying different numbers. It was improved by Ursus who operated with the factors of the absolute term. Just what the nature of the process was is not sufficiently explained by Ursus, and has been the subject of conjecture on the part of Cantor[1] and Eneström[2].

That the problem of approximate solution was forcing itself upon the attention of algebraists is still further evident from the work of Joost Bürgi[3] (1552-1632), a Swiss who figures in the invention of decimal fractions, logarithms, and the pendulum clock. Interested in the construction of trigonometric tables, he finds graphically that the side of a regular nonagon, determined by the equation

$$9-30x^2+27x^4-9x^6+x^8=0$$

lies between .68 and .69. Then he proceeds to closer values by a *regula duorum falsorum* which yields the first time 40 as the next two digits and the second time four more digits 4029, making the final result $x=.68404029$.

This problem of finding the chord of the nth part of a circular arc by means of equations of higher degrees was studied also by Pitiscus in his *Trigonometria* of 1612, who followed the line of thought marked out by Bürgi.

In Belgium we find Simon Stevin (1548-1620) of Bruges, at one time, busy with approximate solution[4]. He claims for himself the invention of the following process which yields the required root, one digit at a time. To solve

$$x^3=300x+33915024$$

[1]Cantor *op. cit.* Vol. 2, 2nd ed., p. 626.

[2]*Bibliotheca Mathematica*, (3) 7, 1906–'07, p. 390.

[3]Wolf, *Gesch. d. Astronomie*, Muenchen, 1877, pp. 272–276; M. Cantor *op cit.* Vol. II, 2nd Ed., 1900, pp. 646–648.

[4]Stevin *Oeuvres*, Leiden, 1634, Part I., p. 88: see also M. Cantor, *op. cit.* Vol. II, 2nd Ed., 1900, p. 628.

he puts in succession $x=1$, 10, 100, 1000, and finds that all values of x, except the last, make the left member of the equation smaller than the right member. Hence x lies between 100 and 1000. Try next $x=200$, 300, 400; it is seen that 300 is too small and 400 is too large. Hence the first digit of the root is 3. To ascertain the second digit, take $x=310$, 320, 330; the root lies between 320 and 330, hence the second digit is 2. Next it is found that 321, 322, 323 are too small, but that 324 is exact, and is therefore the value of the required root. When the root is not an integral number, Stevin proceeds to an approximation, using decimal fractions. As is well known, Stevin was an enthusiast on decimal fractions and has a firmer claim on their invention than anyone else. Stevin's method was nothing but successive trial of different numbers. Yet it found some acceptance, for we shall find traces of it in the eighteenth century.

We have seen that the sixteenth century produced a number of great algebraists who worked more or less on affected numerical equations. Italy had her Cardan, Switzerland had her Bürgi, Belgium her Stevin, but the greatest of all belongs to France—Francis Vieta. His researches initiate a new era.

SUMMARY.

Before Vieta the following results were reached:

1. Methods of approximation to the square, cube, fourth and even higher roots of numbers were devised which are substantially the methods used today. Also special formulas yielding approximate values of square and cube roots were used by Heron, by the Hindus and Arabs, and by Europeans drawing from Arabic sources.

2. Isolated attempts to approximate to the roots of affected equations were made by an Arabic and a few European writers.

GENERAL REMARKS.

Thus far, the methods of solving affected equations by approximation have sprung into being independently in different parts of the country very much as do thinly scattered flowers in a large field. But from now on we shall be able to trace in many cases an interdependence, showing cross-fertilization. Often it will be possible to see how the creations of one author influenced the work of later authors.

PART II. VIETA, NEWTON, LAGRANGE.

Beginning of an interdependent progressive development of methods of solving affected equations. The methods in general use are either laborious or insecure.

To Francis Vieta (1540-1603) more than to others do we owe the epoch-making innovation in algebra of denoting general or indefinite quantities by letters of the alphabet. Vieta arrived at a partial knowledge of the relations existing between the coefficients and the roots of an equation. Unfortunately he refused to avail himself of the negative roots of Cardan. Recognizing only positive roots he could not fully perceive the relations in question. He was in the habit of assigning to letters only positive values, so that some of his algebraic expressions mean less than at first sight they appear to do. On the subject of the approximate solution of equations Vieta achieved more and wielded a wider influence upon later workers than did any other mathematician of his time. The researches in question are contained in a work published by Ghetaldi as editor, with Vieta's consent, at Paris in 1600, under the title: *De numerosa potestatum purarum atque adfectarum ad exegesin resolutione tractatus.* Vieta printed his works at his own expense and distributed them as gifts. The original editions are scarce, but in 1646 a collection of his writings was published by Schooten. One of the earliest writers of text-books to explain Vieta's procedure was Pierre

Hérigone, in the second volume of his *Cours mathématique*, 1634.[1] Vieta begins with pure equations. Like Stifel, he shows familiarity with the binomial coefficients, and extracts roots of as high an order as the sixth. In solving affected equations, Vieta is satisfied with a single positive root. His mode of procedure is not of the nature of the *regula duorum falsorum*, used by Cardan and Bürgi, but is in closer alignment with the method of ordinary root-extraction than any method of approximation heretofore suggested. Taking $f(x)=k$, where the coefficients are numerical and the signs are so taken that k is positive, Vieta is careful to separate the required root from the rest, then substitutes an approximate value for it and shows that another figure of the root can be obtained by division. A repetition of this process gives the next figure, and so on. Thus, in $x^5-5x^3+500x=7905504$, he takes $r=20$ for the approximate root. He computes next $7905504-r^5+5r^3-500r$ and divides the result by a value which in our modern notation takes the form

$$|(f(r+s_1)-f(r))|-s_1{}^n$$

where $f(x)$ is the left side of the equation $f(x)=k$, n is the degree of the equation and s_1 is a unit of the denomination of the digit next to be found. Thus if the required root is 243, and r has been taken to be 200, then s_1 is 10; but if r is taken as 240, then s_1 is 1. In the above example the divisor is 878295, and the quotient yields s, the next digit in the root, equal to 4. Thus $x=r+s=20+4=24$, the required root.

The roots which Vieta finds are all commensurable, although the same process would apply to incommensurable roots.

Vieta's process is explained inaccurately by modern

[1] A. De Morgan, "Notices of the Progress of the Problem of Evolution," in *The Companion to the (British) Almanac* for 1839, p. 36. This article, which we shall quote frequently, contains much historical information about Vieta, Oughtred, Harriot, Wallis, Newton, and especially Horner. The article is very valuable, even though some of De Morgan's statements need qualification in the light of more recent historical research.

historians, including H. Hankel[1] and M. Cantor.[2] By them it is made to appear as identical with the procedure given later by Newton. The two are not the same. The difference lies in the divisor used. We have given a general expression for Vieta's divisor; Newton used $f^1(r)$. In the above example Vieta's divisor is 878295, while Newton's divisor is 794500. The inaccuracy in question consists in attributing to Vieta the same divisor as that used by Newton. The error probably arose from the fact that in some quadratic equations given by Vieta the two divisors happen to be the same in value. De Morgan[3] describes Vieta's divisor as being $f(r+1)-f(r)-1$. This does not fit the case except when the new digit to be found is in the unit's place. Strange to say, we have not been able to find any historian who gives a correct general expression for Vieta's divisor. The advantage of Vieta's divisor is that it is more reliable than Newton's; its very great disadvantage lies in the large amount of computation called for. It is interesting to note that in pure root extraction, Vieta uses the very same divisor. Thus, in finding the sixth root of 191,102,976 the divisor used is 21766120, the root being 24.

Vieta possessed a uniform mode of procedure for finding roots of pure numbers and of equations. This is not conceded by Cantor, but if Cantor had had in mind a correct general expression for Vieta's divisor, this fact would have been evident. Vieta gives numerous examples of his definite fixed arrangement of numerical work.

Vieta's approximate solution of equations was used in France by Claude Francois Milliet Dechales in his *Mundus mathematicus*, Lyon, 1674, 1690, but received, as we shall see, earlier and special attention in England.

But before we cross the channel, we desire to speak of some further discoveries on the Continent. In the first place

[1]Hankel, *op. cit.* pp. 369, 370.
[2]Cantor, Vol. II, 1900, pp. 640, 641.
[3]*Comp. to Brit. Almanac*, 1839, p. 37.

we call attention to a process devised by the Italian Pietro Antonio Cataldi in 1613 for the extraction of square roots by expressing the result in the form of a continued fraction.[1] It is of interest as a forerunner of a process of solving affected numerical equations by continued fractions, invented a century and a half later by Lagrange.

We come now to speak of a capital discovery which lies on the border line of our subject, namely Descartes' Rule of Signs. It was in 1637 that René Descartes (1596-1650) published his famous *Discours de la méthode*, containing among others an essay of 106 pages on geometry. In this geometry is given, without proof, his celebrated rule: An equation may have as many positive roots, as it has variations of sign, and a complete equation as many negative roots as it has permanences of sign.[2] Descartes gives the rule after pointing out the roots 2, 3, 4, -5 and the corresponding binomial factors of the equation $x^4-4x^3-19x^2+106x-120=0$. His exact words are as follows:

"On connoît aussi de ceci combien il peut y avoir de vraies racines et combien de fausses en chaque équation: à savoir il y en peut avoir autant de vraies que les signes + et − s'y trouvent de fois être changés, et autant de fausses qu'il s'y trouve de fois deux signes + ou deux signes − qui s'entre-suivent. Comme en la dernière, à cause qu'après $+x^4$ il y a $-4x^3$, qui est un changement du signe + en −, et après $-19x^2$ il y a $+106x$, et après $+106x$ il y a -120, qui sont encore deux autres changements, on connoît qu'il y a trois vraies racines; et une fausse, à cause que les deux signes − de $4x^3$ et $19x^2$ s'entre-suivent."

Unfortunately Descartes did not fully elucidate this rule. His statement lacks completeness. For these reasons he has been frequently criticized. Wallis claimed that Descartes

[1]Cataldi, *Trattato del modo brevissimo di trovare la radice quadra delli numeri* in Libri IV, 92, Note 1, and 93 Note 1. See also Favaro's article in *Bullettino Boncompagni* VII, pp. 534–547; Cantor II, 1900, p. 762.

[2]Descartes *La Géométrie*, Livre Troisieme.

failed to notice that the rule breaks down in case of imaginary roots, but Descartes does not say that the equation *always has*, but that it *may have* só many roots. It is true that Descartes does not consider the case of imaginaries directly; but further on, in his Geometry, he gives ample evidence of his ability to handle the case of imaginaries.

The question arises, did Descartes receive any suggestion of his rule from earlier writers? There is no evidence that he did, but he might have received a hint from Cardan,[1] whose remarks on this subject have been summarized by Enestrom[2] as follows: If in an equation of the second, third or fourth degree, (1) the last term is negative, then one variation of sign signifies one and only one positive root, (2) the last term is positive, then two variations indicate either several positive roots or none. Cardan does not consider equations having more than two variations.

The Rule of Signs was for many years erroneously attributed to Harriot. The blame for introducing this error is usually charged to Wallis, but Wallis is not the first to commit the mistake. Before him the Rule of Signs was attributed to Harriot by Leibniz.[3]

Proofs of Descartes' Rule of Signs have been given by many writers. Leibniz pointed out a line of proof, but did not actually give it.[4] In 1675 Jean Prestet published at Paris in his *Elemens des mathematiques* a proof which he afterwards acknowledged to be insufficient.[5] In 1728 Johann Andreas Segner published at Jena a correct proof for equations having only real roots.[6] Many years later he gave a general demonstration,[7] based on the consideration that multiplying a polynomial by $x-a$ increases the number of variations by at

[1] Cardano IV., 323.
[2] *Bibliotheca Mathematica*, (3) 7, 1906–'07, p. 293.
[3] *Idem* (3) 10, 1910, p. 80.
[4] *Idem* (3) 7, p. 306.
[5] *Bibliotheca Mathematica*, (3) 7, 1906–07, p. 300.
[6] *Idem* (3) 7, p. 307.
[7] *Histoire de l'Académie de Berlin.* Année 1756, pp. 292–299.

least one. Other proofs were given by Jean Paul de Gua de Malves,[1] Isaac Milner,[2] Friedrich Wilhelm Stübner,[3] Abraham Gotthelf Kaestner,[4] Edward Waring,[5] J. A. Grunert,[6] K. F. Gauss,[7] Laguerre.[8] Gauss showed that, if the number of positive roots falls short of the number of variations, it does so by an even number.[9] Laguerre extended the rule to polynomials with fractional and incommensurable exponents, and to infinite series.

Perhaps the earliest French follower of Descartes was Florimond de Beaune (1601-1652). Among his posthumous papers is the one *De limitibus aequationum*,[10] in which he establishes upper and lower limits for the roots of quadratics and cubics. In $x^2-lx+m^2=0$, $m^2/l<x<l$; in $x^3+lx^2-m^2x+n^3=0$, $n^3/m^2<x<m^2/l$. A Dutch follower of Descartes was Johann Hudde (?-1704) of Amsterdam, the author of a rule named after him on equal roots.[11] If the terms of an equation which has two roots equal to each other are multiplied, respectively, by the terms of any arithmetical progression, then one of the said roots reappears in the new equation thus obtained. A demonstration to this remarkable rule was furnished by Hudde himself[12] and, over a century later, again by Fagnano.[13]

[1] *Histoire de l'Académie des Sciences de Paris pour* 1741, pp. 72–96. See Cantor III, 1901, pp. 578, 579.

[2] Phil. Transactions (London) Vol. 68, year 1778, pp. 380–388.

[3] Cantor, III, 1901, p. 583.

[4] *Demonstratio theorematis Harrioti*, 1745.

[5] *Meditationes Algeb.*, ed. tertia, 1782, p. 110.

[6] Crelle's *Journal*, Vol. II, 1827, pp. 335–344.

[7] Crelle's *Journal*, Vol. III, 1828, pp. 1–4.

[8] *Oeuvres de Laguerre*, Vol. I, 1898, p. 3.

[9] K. F. Gauss, *Werke* 3, p. 67.

[10] Descartes, *Geom.* 1659, II, pp. 121–152. De Beaune's articles are reprinted in Maseres' *Scriptores Logarithmici*, Vol. 6, 1807, pp. 217–263. See also Cantor, II, 1900, p. 800.

[11] Letter, *De maximis et minimis*, January, 1658, printed by Van Schooten in Descartes' *Geom.*, 1659, I, pp. 433–439, 507–509.

[12] See Enestrŏm's statement of Hudde's proof in the *Bibliotheca Mathematica* (3) 10, 1910, pp. 267, 268.

[13] *Nova acta eruditorum*, 1776, p. 1–11. Another rule for detecting equal roots was given by John Hellins in the *Philosoph. Transactions*, 1782, London, pp. 417–425

Crossing the channel to England, we find the earliest great algebraist there to be Thomas Harriot (1560-1621). His posthumous work, the *Artis analyticae praxis*, 1631, was written long before its date of publication. Of special interest is Harriot's modification of Vieta's process of root approximation. This is a real improvement. Harriot does not take $|(f(r+s_1)-f(r))|-s_1^n$ as the divisor for finding the next digit as did Vieta, but forms only so much of this as is necessary to determine that digit. Worthy of mention is also Harriot's habit of removing the second term of the equation before beginning his approximation, a step which proved advantageous with his arrangement of the work. De Morgan's statement that Harriot gives examples of affected equations with roots computed to three digits, while Vieta gives examples with roots of only two digits, needs qualification as regards Vieta. Of 32 examples worked by Vieta in full, 7 answers are expressed in 3 digits.

An indication of interest aroused in our subject is found in the statement[1] that William Milbourn, curate at Brancespeth near Durnham, was well versed in algebra, having extracted the approximate root of an equation of the fifth degree before he had seen Harriot's work.

The second Englishman to write on numerical equations was William Oughtred. Wallis says[2] that Oughtred, in his *Clavis* (1631), refers readers to his *Exegesis Numerosa*, or *Numerical Solutions of Affected Equations*, a separate treatise, subjoined in later editions to his *Clavis*. It is thus subjoined to the editions of 1647 and 1648. Oughtred's method of solution is that of Vieta, as distinguished from that of Harriot, but neither Vieta nor Harriot are mentioned in the text. If one repeats the steps in the operations, one sees that in the hands of Oughtred algebraic manipulation was still in a crude state. Thus, he computes $ab+ac$, rather than $a(b+c)$.

[1] *Penny Cyclopaedia*, Art. "Horrocks."

[2] *Treatise of Algebra*, 1685, p. 68.

Before giving examples of solutions by Vieta's method, Oughtred shows how one may get by easy processes of trial and error the first, or the first two digits of a root of a rather simple equation, say $x^4-72x^3+238600x=8725815$. To find the first digit, he takes $x^3+238.6-7.2x^2=x)872.5$, and tries $x=4$ and $x=5$, and finds the first digit to be 4. To find the second digit, he takes $x^2-x)238600-72x=x^2)8725815$. He tries $x=47$ and $x=48$, and finds that x is 47. He explains, next, how the last computation may be done by logarithms. Thereby he established for himself the record of being the first to use logarithms in the solution of affected equations.

The next improvement in Vieta's process is given in the celebrated *Algebra* of John Wallis (1616-1703), published in 1685 and 1693. In Chapter 62 he solves a quartic equation which arises in the solution of a problem proposed by Dr. Pell to Colonel Silas Titus, and by him to Dr. Wallis, who, as De Morgan remarks, seems to have considered it a sort of challenge from Pell, and has discussed it in a most masterly manner. The problem calls for the determination of a, b and c in the equations $a^2+bc=16$, $b^2+ac=17$, $c^2+ab=18$. In Wallis' solution of the quartic appears for the first time the contraction of the divisors and remainders. By this important improvement he extracts the root of the quartic to 17 places. He uses Oughtred's marks of explanation. De Morgan solves the same quartic[1] for the purpose of showing the vast superiority of Horner's method over that of Vieta, even as improved by Wallis. From what Wallis says it would seem that Vieta's method was then commonly known and practiced. This appears also from the fact that an edition of Oughtred's *Key to the Mathematicks* was published by Halley as late as 1702. Oughtred's text must have done more than any other work to popularize the method in England.

It would seem that at this time investigations were being

[1] *Comp. to the British Alm.*, 1839, p. 51.

carried on in England on the solution of numerical equations, which are not generally known to historians and are now attributed to later writers. A paper by John Collins in the Philosophical Transactions,[1] on "Improvements in England in the resolution of equations in numbers" gives an account of these. Even Cantor and De Morgan nowhere mention this article. Collins tells of what "hath been observed by divers of this Nation." If in an affected equation, $f(x)=N$, x be given successively values that are in arithmetical progression, then the absolute numbers N (the *homogènes de comparaison* of Vieta) are such that their first, second or third differences, etc., imitate the laws of the pure powers of an arithmetic progression of the same degree, the nth differences being equal. Thus, in the equation, $x^3-3x^2+4x=N$,

If x be =	then N will be found to be	1. Dif.	2. Dif.	3. Dif.
10	740	218		
9	522		48	
8	352	170		6
7	224	128	42	6
6	132	92	36	

Thus the third differences are here equal, as in the cubes of an arithmetical progression. "How to find the greatest product of an arithmetical progression of any number of terms having any common difference assigned, contained in any number proposed, is shewed by Pascal in his tract *du Triangle Arithmetique*, where he applies it to the extraction of the roots of simple powers." "When you have a *Majus* and *Minus*, you may interpole as many more terms in the arithmetical progression as you will," then compute the absolute term. After a rough approximation to the root is secured, "the general method of Vieta and Harriot runs away more easily." Collins refers also to a "more subtile kind of interpolation" as used in Briggs' *Arithmetica logarithmica* and to other proposed processes. The method of differences may

[1] *Phil. Trans.* IV., 1669, p. 929.

well serve the purpose of locating the real roots, but the efforts to raise it to a method of close approximation were not crowned with success.

On account of his zeal for collecting and diffusing scientific information, Collins has been called the "English Mersenne." In his letters he frequently talks of the solution of numerical equations,[1] says that Pell believed in the possibility of constructing tables for solving equations, that Pell for thirty years past had "forsaken Vieta's method, and solved equations by the table of logarithms, etc.," and "he intends to write a treatise of this argument." But Pell never fulfilled his promises in this matter.

The method of approximation given by Sir Isaac Newton (1643-1727) was first outlined by him in his *De analysi per aequationes numero terminorum infinitas.*[2] He placed this tract in the hands of his teacher, Isaac Barrow, in 1669, and Barrow sent it to John Collins, who greatly admired it. Barrow urged Newton to have it printed, but Newton's modesty prevented his compliance. It was not published until thirty-five years later, in 1704. The tract remained unknown, except to his friends and the correspondents of John Collins. It contains the principle of fluxions partly worked out and touches upon the solution of numerical equations by successive approximations. Newton gives only one example, namely the now famous cubic $y^3-2y-5=0$. He assumes that an approximate value is already known, which differs from the true value by less than one-tenth of that value. He takes $y=2$. Thereupon $y=2+p$ is substituted in the equation which becomes then

$$p^3+6p^2+10p-1=0.$$

Neglecting the higher powers of p, he gets $10p-1=0$; taking $p=.1+q$, he gets

$$q^3+6.3q^2+11.23q+.061=0.$$

[1] See *Correspondence of Scientific Men of the 17th Century*, Oxford, 1841, Vol. I, pp. 155, 216, 243; Vol. II, 198, 218, 472 and other places.

[2] *Opuscula Newtoni* I, 10–12.

All the more may higher powers of the unknown quantity be neglected now. From $11.23q+.061=0$ he gets $q=-.0054+r$, and by the same process, $r=-.00004853$. Finally $y=2+.1-.0054-.00004853=2.09455147$.

Newton arranges his work in a paradigm. He seems quite aware that his method of approximation may fail. If there is doubt, he says, whether $p=.1$ is sufficiently close to the truth, find p from $6p^2+10p-1=0$. Newton does not show that even this latter method will always answer. This expedient of considering terms of the second degree is frequently resorted to by later writers, either to secure greater accuracy in each step or to attain greater safety, or both.

Another tract of Newton, the *Methodus fluxionum*, was at one time planned for publication in 1671, but was not published until 1736. The tract begins with the solution of equations, in close agreement with what is given in the *Analysis per aequationes*. It was many years before Newton's method of approximation was duly appreciated. In 1673 and 1674 appeared John Kersey's *Algebra*, which was looked upon as classic. In announcements of this work, published by Wallis and Collins in 1672 in the Philosophical Transactions, no mention is made of Newton's research. It was not until 1685 that Newton's method of approximation reached the press. It was in that year that Wallis brought out the first edition, in English, of his *Algebra*. This edition, as well as the Latin edition of 1693, explains in Chapter 94 Newton's process of solving $y^3-2y=5$, as well as Newton's expression of the value of y in terms of a and x by a rapidly converging series, the equation being $y^3+axy+aay-x^3-2a^3=0$. The two equations are treated in much the same manner. Wallis does not praise Newton's method over the older; he merely states that it "is very different from that of Vieta, Oughtred, and Harriot, which is commonly received." From now on, however, Newton's method, or Raphson's and Halley's modification of it, begin to be used to the exclusion of earlier ones.

Five years after the first publication of Wallis' *Algebra*, there appeared, in 1690, in London, a tract by Joseph Raphson[1] (1648-1715), a Fellow of the Royal Society, bearing the title *Analysis aequationum universalis*. A second edition, with an appendix, appeared in 1697. The method of approximation explained in this tract closely resembles that of Newton. The only difference is this, that Newton derives, as we have seen, each successive step p, q, r, of approach to the root, from a *new* equation; while Raphson finds it each time by substitution in the original equation. In Newton's cubic $x^3-2x=5$ Raphson would start with the value 2 and find, as did Newton, the first correction. To find the second correction, Raphson would not use the new equation $x^3+6x^2+10x-1=0$, but substitute $2.1+q$ in the given equation, finding $q=-.0054$. He would then substitute $2.0946+r$ in the given equation, finding $r=-.00004852$, and so on. Wallis printed extracts from Raphson's tract in the Latin edition of his *Algebra* (1693).

Raphson's method was used in the eighteenth century quite extensively. Raphson does not mention Newton; he evidently considered the difference sufficient for his method to be classed independently. He does mention Vieta. In our opinion, Raphson's paper is of much greater historical interest than is ordinarily attached to it. Its importance lies in the fact that the process which in our modern texts goes by the name of "Newton's method of approximation" is really not Newton's method at all, but Raphson's modification of it. The *form* now so familiar, $a-\frac{f(a)}{f^1(a)}$ was not used by Newton, but was used by Raphson. To be sure, Raphson does not use this notation; he writes $f(a)$ and $f^1(a)$ out in full

[1]Or "Ralphson" as the name is printed in Cunn's edition of Raphson's translation into English of Newton's *Universal Arithmetick*, London, 1728. That Joseph Ralphson and Joseph Raphson are the same individual has been proved by Miss Maria Leonard who pointed out that Halley in a Latin article of 1694 refers to "Raphson," while in Cunn's English translation of that article the name is given "Ralphson."

as polynomials. Nor does Raphson find the first derivative by the rule of the calculus; his operations are purely algebraical. He gives "canons" or "theorems" for the forms of the fractions, in which he writes down the polynomials $f(a)$ and $f^1(a)$ for each equation up to that of the tenth degree inclusive. A modern reader finds it odd to see Raphson express g^{10} by writing out each of the ten factors.

In view of the historical facts set forth here, it is doubtful whether this method of approximation should be named after Newton alone. In the first place, the process actually given by Newton, though not identical to that of Vieta, closely resembles it, so that the honor of invention falls largely on Vieta. In the second place, Newton did little to develop his method; he solved the cubic $x^3-2x=5$, and that was all. That Raphson worked independently of Newton we doubt. But his version of the process represents what Lagrange recognized as an advance on the scheme of Newton. The method is "plus simple que celle de Newton;"[1] it is essentially the form which the process has assumed in modern mathematics. It would seem, therefore, that the "Newton-Raphson method" would be a designation more nearly representing the facts of history than is "Newton's method." We shall use the former designation.

Nearly all eighteenth century writers and most of the early writers of the nineteenth century carefully discriminated between the method of Newton and that of Raphson. Then appear writers like Euler, Laplace, Lacroix and Legendre, who explain the Newton-Raphson method, but use no names. Finally, in a publication of Budan in 1807,[2] in those of Fourier of 1818 and 1831,[3] in that of Dandelin in 1826,[4] the Newton-

[1] Lagrange, *Résolution des équat. num.*, 1798, Note V, p. 138.

[2] *Nouvelle méthode pour la résolution d. équat. num.*, Paris, 1807, p. 78.

[3] *Bull. d. sciences par la société philomatique de Paris*, année 1818, p. 61; Fourier, *Analyse des équations déterminées*, 1831, p. 169, 173, 177.

[4] *N. mémoires d. l'académie r. d. sciences et belles-lettres de Bruxelles*, T. 3, 1826, pp. 28, 29.

Raphson method is attributed to Newton. The immense popularity of Fourier's writings led to the universal adoption of the name "Newton's method" for the Newton-Raphson process.

The solution of numerical equations was considered geometrically by Thomas Baker in 1684 and Edmund Halley (1656-1742) in 1687, but in 1694 Halley "had a very great desire of doing the same in numbers." He began by generalizing, so as to apply to roots of any order, certain algebraic expressions yielding approximate cube and fifth roots of numbers given in 1692 by the French author Thomas Fantet de Lagny (1660–1734), in his *Méthodes nouvelles et abrégées pour l'extraction et l'approximation des racines.* Halley was then led to a method of solving affected equations[1] which he considered more compendious than Raphson's. Let a be assumed as near the required root as possible. Substitute $a+e$ for x, and in the resulting expression, $0=b+se+te^2+\ \cdot\ \cdot$, reject powers of e above the second. Then solve the quadratic for e. Of the two values of e thus obtained, select the one suggested by the linear relation $0=b+se$. To avoid the drudgery of root-extraction, he follows De Lagny's idea of approximate solution, using the formula $\sqrt{a^2\pm b}=a\pm ab\div(2a^2\pm\frac{1}{2}b)$.

The only difference between Halley's and Newton's methods is that Halley solves a quadratic equation at each step, Newton a linear equation. The use of a quadratic is more laborious, but usually also more exact. For a time Halley's method was received with favor. His paper was republished in the *Miscellanea Curiosa*, London, Vol. II., 1700, in Harris' *Lexicon Technicum*, in Holliday's *Syntagma Mathesos*, London, 1745, and in the second English edition of Newton's *Universal Arithmetick*, 1728.

While in 1692 De Lagny had touched on approximate methods of extracting roots of numbers, in 1705 and 1706 he

[1] *Philosophical Transactions* No. 210, 1694, p. 136.

took up the solution of equations.[1] He proceeds to outline the method of differences which we have already seen described 36 years earlier in England by John Collins. De Lagny does not express indebtedness to English writers, nor have we found any indications of English influence. While Collins' article simply contains gossip as to what has been done in England, without proper elaboration of details, De Lagny explains the method more systematically, but illustrates it only by solving quadratics. One device of De Lagny seems new. He transforms an equation into one whose roots are multiplied by, say 100, then by the method of differences, locates the root between two successive integers, which yields the root of the original equation correct to within .01. We may also state here that the method of differences was discussed in 1767 by Lagrange.[2] In his second article, De Lagny solves trinomial cubics by series.

In 1690 appeared the *Traité d'algèbre* of Michel Rolle (1652-1719), an author fond of strange words and odd notations which have prevented his work from becoming generally known. Rolle shows how to transform an equation so that all coefficients become integral and the coefficient of the highest power becomes unity, or so that all roots have their signs changed, or so that the signs (of certain equations) become alternately plus and minus. Of interest is his "method of cascades." Taking the largest negative coefficient $-g$, he divides g by the coefficient of the highest power of the unknown, then adds 1 to the quotient and enough more to get a positive integer h. Here he recognizes h as a superior limit of the positive roots. He takes 0 and h as the extreme limits or "hypotheses" of the positive roots. Any two values of the variable which give to $f(x)$ opposite signs are called "hypotheses." He then finds intermediate "hypotheses" or limits by taking the arithmetic mean of the

[1] *Histoire de l'Académie des sciences*, Année, 1705, pp. 277–300: année 1706, pp. 296–319.

[2] *Résolution des équations numériques*, 1798, p. 19.

previous limits and then testing for the location of the roots. By repetition of this process approximations to a root may be made. The process is very cumbrous. These considerations led him to the "method of cascades." In an equation in v which has alternating signs, put $v=x+z$ and arrange the result according to descending powers of x. The coefficients of x^n, x^{n-1}, . . ., when equated to zero, are called "cascades."

The modern reader recognizes these "cascades" as the successive derivatives of the original equation in v, each put equal to zero. Now comes Rolle's theorem: The roots of any Cascade, beginning with the last cascade and ascending to the original equation, are always hypotheses (limits) of the cascade of the next higher grade. In case of imaginary roots, this theorem needs restriction, as was recognized by Rolle. The modern version of it is: Between two successive roots of $f^1(v)=0$ there cannot be more than one root of $f(v)=0$. To ascertain the root-limits of a given equation, Rolle begins with the cascade of lowest degree and ascends, solving each as he proceeds. The process is very laborious. In his *Algèbre* he gives no demonstrations of his theorem, but he is said to have attempted proofs in another publication issued soon after;[1] but which is so rare that none of the historical writers have had the opportunity to examine it. What modern texts call Rolle's theorem is quite different from the theorem published by Rolle in his *Algèbre*. As pointed out by Eneström,[2] the modern theorem[3] is given in restricted form in Ch. Reyneau's *Analyse demontrée*, (I, p. 290), Paris, 1708. This author refers to Rolle for his elaborate presentation of the theory of "cascades." From that fact Eneström conjectures that Rolle himself gave the theorem now known by his name

[1]Cantor, Vol. III, 1901, p. 123.

[2]*Bibliotheca Mathematica* (3) 7, p. 302.

[3]Reyneau's statement is thus: "Les racines d'une équation, dont toutes les racines sont réelles, positives et inégales, sont les limites de l'equation nouvelle qui vient de la multiplication de chaque terme de la premiere par le nombre qui est l'exposant de l'inconnue de ce terme, et de son dernier terme par zero."

in the publication above referred to as having been hitherto inaccessible to historians.

In 1707 the *Arithmetica universalis* of Sir Isaac Newton was published; it contains among its rich material some references to our subject. "You may know almost by this rule how many roots are impossible;" then follows the famous Newton's rule on the number of real and imaginary roots which remained without proof until Sylvester established in 1864 a general theorem which includes Newton's rule as a particular case. However, some light upon the nature of Newton's rule was thrown not long after the appearance of the Arithmetica universalis, by Colin Maclaurin (1698-1746)[1] and George Campbell,[2] who published interesting papers on imaginary roots. The tests which they set labor under the restriction of not revealing the existence of more than two imaginary roots in an equation.

Newton states Descartes' rule of signs in accurate form and gives formulæ expressing the sum of the powers of the roots up to the sixth power and by an "and so on" makes it evident that they can be extended to any higher power. Newton's formulæ take the implicit form, while similar formulæ given earlier by Albert Girard take the explicit form, as do also the general formulæ derived later by Waring. Newton's formulæ were derived by the method of induction by A. G. Kaestner in an article prepared in 1757 but not published until 1771.[3] Newton uses his formulæ for fixing an upper limit of real roots; the sum of any even power of all the roots must exceed the same even power of any one of the roots. The $2m$*th* root of the sum of the $2m$*th* powers of the roots exceeds the largest root by an amount which becomes smaller, the larger m is taken. Newton finds limits also in another way: A number is an upper limit, if, when

[1] *Phil. Transactions* Vol. 34, pp. 104–112, Vol. 36, 1729, pp. 59–96.

[2] *Phil. Transactions* Vol. 35, 1728, pp. 515–531.

[3] *Dissertationes math. et phys.*, Altenburgi, 1771, p. 1–8.

substituted for x, it gives to $f(x)$ and to all its derivatives the same sign.

A well-known upper limit for the roots of an equation was established in 1748 by Colin Maclaurin[1]. He proved that such a limit is obtained by adding unity to the absolute value of the largest negative coefficient of the equation.

In 1717 Brook Taylor[2] (1685–1731) made an application of the celebrated series which bears his name to the solution of numerical equations. He assumes that by the intersection of curves or by some other device a rough approximation to a root of the equation $f(x)=0$ has been found. Let a be this approximation, also let $f(a)=k$, $f'(a)=k'$, $f''(a)=k''$, and $x=a+s$. He expands $0=f(a+s)$ by his theorem, discards all powers of s above the second, substitutes the values of k, k', k'', and then solves for s. By repetition of this process, close approximations are secured. It is asserted without proof that the values of s yield twice as many decimal places as were accurate in a at the start, that $x=a+s$ is therefore accurate to three times as many decimal places as is a alone. Taylor gives in this article essentially Halley's method of 1694, expressed in the language of fluxions. In each step of the approximation Taylor retains terms involving s to the second power, while the Newton-Raphson procedure retains only those involving s to the first power. But there is another difference between Taylor and his predecessors. Taylor makes the important observation that the method of fluxions solves not merely the ordinary equations, but also equations involving radicals or transcendental functions.

The first application of the Newton-Raphson process proper to the solution of transcendental equations was made by Thomas Simpson (1710-1761), in his *Essays . . . on Mathematicks*, London, 1740. He presents the Newton-Raphson method there as a "new method." The exposition is in the language of the calculus (fluxions).

[1] Maclaurin, *Treatise of Algebra*, London, 1748, p. 172.

[2] *Philosophical Transactions*, 1717, Vol. 30, pp. 612–622.

The use of the calculus in the discussion of methods of approximation appears also in researches carried on by le Marquis de Courtivron[1] (1715-1785) who simplified the transformations in Newton's process by using the rules of differentiation for finding the coefficients of the transformed equation. He then expresses the roots in the form of an infinite series, thereby reaching results similar to results communicated by Euler. The convergence of the series fails to receive proper attention.

Euler made further application of the calculus to the solution of numerical equations in 1755 in his *Institutiones calculi differentialis*, sec. 224, 234, 235. He used Taylor's Theorem, expressing it, of course, in the notation of Leibniz.

De Gua de Malves (1712-1785) gave two proofs of Descartes' rule of signs,[2] as already stated, and he deduced from it some interesting consequences as to the connection between zero-coefficients and imaginary roots which amount to the following: The absence of $2m$ successive terms indicates $2m$ imaginary roots, while the absence of $2m+1$ successive terms indicates $2m+2$ or $2m$ imaginary roots, according as the two terms between which the deficiency occurs have like or unlike signs. He also established the theorem that an equation can never have all its roots real, unless the equations of inferior degree, gotten by differentiation, have all their roots real also. He endeavored to establish also other criteria for complex roots involving relations between the coefficients of the equation, as Newton, Stirling, Maclaurin and Campbell had done.

During the eighteenth century extensive researches were carried on upon the theory of equations. This fact is evident as soon as we mention the names of Waring, Euler, Clairaut, Bézout, Lambert, Séjour, Vandermonde, Marguerie, Malfatti, Bring, Hulbe, Segner, Mourraille, and finally the greatest

[1] *Histoire de l'Académie Roy. des Sciences*, Année 1744, *mémoires*, pp. 405–414.

[2] *Histoire de l'Académie des Sciences de Paris.* Année, 1741, pp. 72–96. See also a second paper of the same year, pp. 435–494.

name of all, Lagrange. Several of these worked in the special field of numerical equations.

Edward Waring (1734-1798), published his first important book, the *Miscellanea analytica*, in 1762, two years after his election to the professorship of Mathematics at Cambridge. But as early as 1757 he had found the necessary and sufficient relations which must exist between the coefficients of a quartic and quintic, for two and for four imaginary roots. Such relations were published by him in 1764 in the *Philosophical Transactions*. Waring was the first to do this for the quintic. These criteria were derived by a new transformation, namely the one which yields an equation whose roots are the squares of the differences of the roots of the given equation.[1] He gives other modes of searching for imaginary roots and deduces formulæ for the sums of powers of the roots by a new process. Formulæ for the sums of powers of the roots, different from Newton's, had been derived also by J. H. Lambert.[2] To effect the separation of the roots, Waring transforms an equation into one whose roots are the reciprocals of the differences of the roots of the given equation. The reciprocal of the largest of the roots of the transformed equation is less than the smallest difference between any two roots of the given equation. Let A be this reciprocal, and π an upper limit of the roots of the given equation, then the subtraction of A, $2A$, $3A$, etc., from π will give values which separate all the real roots.[3]

In the *Meditationes algebraicæ* which Waring brought out in 1770, eight years after the Miscellanea analytica, the subjects contained in the earlier work are treated more fully and new results are added. Starting with Rolle's researches he deduces new rules on the separation of the roots and the detection of imaginary roots.[4] In this work of Waring for

[1] *Miscellanea Analytica*, p. 17.

[2] *Acta Helvetica*, Basileae, Vol. III, 1758, pp. 128–168.

[3] *Miscellanea analytica*, p. 21.

[4] *Op. cit.*, p. 68. Another English writer on this topic is Isaac Milner, who contributed a paper to the Philosoph. Transactions, Vol. 68, for the year 1778, London, 1779, pp. 380–388.

the first time we find a process described for approximating to the values of imaginary roots. If $a+ib$ is an approximate value of x, substitute $x=a+a'+(b+b')i$; expand and retain only the first powers of a′ and b'. Equating real numbers to each other and the imaginary numbers to each other, two equations are obtained which yield rough values for a' and b'.[1] This process is simply Newton's method extended to imaginary roots.

Three times in the eighteenth century the Parisian Academy of Sciences considered the subject of imaginary roots. The first time was in 1741 when De Gua presented papers of which we have already spoken; the second time was when Alexis Fontaine (about 1705-1771) presented his papers with a scheme of detecting imaginary roots.[2] He considers equations as made up of linear factors, real or imaginary, and studies all the combinations which can be formed of such factors. For each system of factors he searches the characteristic relation which must prevail among the coefficients of the equation. He forms tables displaying the different systems and the characteristic relation for each. For the quartic his table exhibits 617 special cases. The idea is practically inoperative and theoretically imperfect.[3] The third time that the Academy discussed this subject was in 1772 when Achille Pierre Dionis du Séjour (1734-1794) discussed the roots of the cubic and quartic in a way that drew out appreciative remarks from Lagrange.[4]

Imaginary roots were also considered about this time by Euler,[5] who established three criteria (two of them previously given by Newton) which, though necessary conditions, are

[1] *Op. cit.*, p. 268.

[2] *Histoire de l'académie des sciences de Paris.* Année, 1747, pp. 665–677; *Mémoires donnés à l'acad. roy. des sciences, non imprimés dans leur temps.* Par M. Fontaine, Paris, 1764, pp. 432–588.

[3] See Lagrange, *Résolution des équat. num.*, Note VII.

[4] *Histoire de l'académie roy. des sciences, année,* 1772, II. Partie, Paris, 1776, pp. 377–456. Lagrange *Oeuvres*, T. XIV, p. 71.

[5] *N. Comm. Petr.* Tom. XIII, pro anno 1768, Petropoli 1769, p. 89–119.

not sufficient, to establish the nature of the roots. Criteria that are both necessary and sufficient were suggested by Lagrange.[1] He institutes tests to see whether the equation has factors x^2-ax+b, where $b<a^2/4$, or not. Imaginary roots are present always and only when such factors exist. Lagrange also derives the familiar criteria of the nature of the roots of the cubic $x^3-Bx+C=0$; all roots are real, two are equal, or two imaginary, according as $4B^3$ is greater, equal to, or less than $27C^2$. He gives similar criteria for the quartic and remarks that Waring had published these results before him.

Among eighteenth century mathematicians interested in methods of approximation was Johann Heinrich Lambert (1728-1777)[2]. In $0=a-bx+cx^2- \ . \ . \ . \ +px^m$, let $x=k+y$ and reject terms involving the higher powers of y. The process is substantially that of Newton and Raphson though their researches are nowhere mentioned and the process appears to be original with Lambert.

The only difference between Lambert's and the Newton-Raphson procedure is that Lambert takes $\frac{kf'(k)-f(k)}{f'(k)}$ as the corrected value of the approximation, while in the Newton-Raphson process, $k-\frac{f(k)}{f'(k)}$ is taken. In other words, the only difference lies in the mode of writing a fractional value.[3]

At nearly the same time as Lambert, Lagrange published his great paper, *Sur la résolution des équations numériques.*[4] He explains the separation of the real roots by substituting for x the terms of the progression, $0, D, 2D, \ . \ . \ .$ where

[1] Lagrange, "Sur la determinatiqn du nombre des racines imaginaires dans les équations literales" in *Nouveaux mémoires de l'acad. roy. des sciences, année* 1777, Berlin, 1779, pp. 111–139; Lagrange, *Oeuvres* T. IV, pp. 343–374.

[2] *Acta Helvetica*, Basileae, Vol. III, 1758, pp. 128–168.

[3] The very same expression as that of Lambert was given before this by a Mr. Wastel of the English Navy Office and published in Harris' *Lexicon Technicum* (1704). See De Morgan in *Companion to the Brit. Alm.*, 1839, p. 52.

[4] *Mémoires de l'acad. roy. des sciences, année*, 1767, Berlin, 1769, pp. 311-352; Lagrange, *Oeuvres* T. 2, pp. 539–578.

D must be less than the least difference between the roots. The computation of D is difficult; Lagrange has suggested three ways: One way in the year 1767, another in 1795 and a third way in 1798. The first depends upon the formation of the equation of the squared differences of the roots of the given equation. This new equation enables him also to determine the number of imaginary roots. It will be remembered that Waring before this had derived this important equation, but in 1767 Lagrange had not yet seen Waring's writings. Lagrange's exposition of this subject is far more elegant than that of Waring. Lagrange finds equal roots by computing the highest common factor between $f(x)$ and $f'(x)$. Lagrange proceeds to develop a new mode of approximation, that by continued fraction. Cataldi had used these fractions in extracting square roots. Lagrange puts $x=p+1/y$, then in the resulting equation he puts $y=q+1/z$, and so on. The value of x thus appears in the form of a continued fraction which yields alternately two kinds of approximate values, one kind always less than the required root, and the other kind always greater. In the case of rational roots, the continued fraction is finite. In the case of irrational roots, the magnitude of the error appears at every step in the process, which is not true in Newton's or Raphson's process. These topics are all discussed much more fully in Lagrange's *Additions au mémoire sur la résolution des équations numérique.*[1]

Lagrange's method of approximation can be used without danger of failure. Unlike the older methods it has no cases of failure. Yet, though theoretically perfect, so that Lagrange could say, "cette méthode ne laisse, ce me semble, rien à désirer," it is of little value in practice, for the root appears in the form of a continued fraction and the computation of it is laborious, notwithstanding certain short cuts suggested by Lagrange. He had a theoretically perfect, though practically an extremely laborious method for finding imaginary

[1] *Mémoires de l'acad. roy. des sciences, année,* 1768, T. 24, Berlin, 1770, pp. 111–180; *Oeuvres* T. 2, pp. 581–652.

roots. If $a+ib$ and $a-ib$ are a pair of such roots, then the equation of the squared differences of the roots has a negative root, $-4b^2$. Find this negative root and from it find b. Substitute $a+ib$ in the given equation; from it derive two equations by equating the real terms and the imaginary terms each separately to zero. For b insert its numerical value. The two last equations have the root a in common, which can be determined by the method of the greatest common divisor. Thus the roots $a\pm ib$ are found. Lagrange explains the case of equal imaginary roots.

The Newton-Raphson process was in great favor with many writers of the eighteenth century. Euler speaks of it as the best known process.[1] In England, Charles Hutton (1737-1823), used it in 1777 in the computation to 15 places of the sine of an arc of 1 minute. He took the equation $a^5-5a^3+5a=b$, where b is the chord of a given arc and a the chord of its fifth part.[2] Hutton says, "I was always of opinion that Raphson's was an easier and readier method of resolving high equations than Halley's, etc., as it is both clearer and requires less time."[3] Francis Maseres (1731-1824) says that it "is, in general, preferable to every other."[4] In 1800 Maseres published *Tracts on the Resolution of Equations.* He was a leader in England of a reactionary movement to dispense with negative and imaginary numbers in algebra. In one article he takes pains to modify Raphson's process, so as to make it conform with his self-imposed restriction upon the number concept. As regards the degree of accuracy obtained by Raphson's processes, Maseres observed, as others have done, that if the answer is correct to n places, the next step in Raphson's process is correct to $2n-1$ or $2n$ places. James Ivory of the Military College at Marlow in 1801 worked

[1] Euler, *Algebra* 2. Theil, St. Petersburg, 1770, Cap. 16, p. 201.
[2] Maseres, *Scriptores Logarithmici* Vol. 6, 1807, 451–474.
[3] *Loc. cit.*, p. 455.
[4] *Loc. cit.* p. 353.

out a method of ascertaining the number of exact figures[1] which involved a laborious modification of Raphson's method.

An interesting text, the *Analysis aequationum*, was published in 1784 in Dublin by Guil. Hales. The author explains how the maximum (and minimum) root may be obtained by computing the 2^{nth} root of the sum of the 2^{nth} powers of the roots. Hales shows also how the presence of imaginary roots is revealed by the successive sums of powers. He explains the method of Newton and Halley and refers to the work of Raphson, Bernoulli, Courtivron, Euler, Taylor and Simpson.

It is well known that the Newton-Raphson method of approximation to the roots of numerical equations, as it was handed down from the seventeenth century, labored under the defect of insecurity in the process, so that the successive corrections did not always yield results converging to the true value of the root sought. The removal of this defect has been attributed to Fourier, and is generally considered among the more important results reached by Fourier on numerical equations. But Fourier was anticipated 50 years by J. Raym. Mourraille.

Newton's method was pronounced insecure by Lagrange. The a priori determination of the conditions under which the method can be used safely seemed to Lagrange difficult, if not impossible.[2] But we shall see that Mourraille had removed these difficulties thirty years before Lagrange issued his book of 1798. Mourraille's researches are contained in his *Traité de la résolution des équations en général* (Marseille et Paris, 1768). This large quarto volume of 445 pages has quite escaped the notice of mathematicians. The only review of it that we have seen is in the *Journal des Scavans* in Amsterdam, March, 1769. We have seen no mention of the book in publications on the solution of numerical equations.

[1]Maseres, *Scriptores Logarithmici*, Vol. 6, pp. 351–359.

[2]Lagrange, *Résolution des équations numériques*, 1798, Note V.

Mourraille was for fourteen years, until 1782, secretary de la classe des sciences of the academy at Marseille. At the time of the French revolution he became mayor of Marseille, and during the political upheavals that followed he was accused of several crimes.[1]

The main object of Mourraille was to perfect Newton's method. He states that he consulted only the researches of Newton, Maclaurin and some other English writers, and the French work (the *Analyse demontrée*) of Reyneau. He was a great admirer of Newton. It is worthy of notice that Newton, and (as will be seen later) Lagrange approached the problem of approximation by purely analytical considerations, while Mourraille and Fourier both introduced also geometrical considerations and thereby both arrived at analytical criteria which are sufficient to insure security in the operation of Newton's method. Mourraille arrives at the general conclusion that one needs only select, as the first approximation, a value A for x, such that the curve is convex toward the axis of x for the interval between A and the root. He shows that this condition is sufficient, but not necessary. With great clearness he explains from a drawing the possibilities of failure of Newton's method. Whether the curve is concave or convex toward the axis of x is determined by the methods of the calculus. Not only did Mourraille anticipate Fourier in the establishment of sufficient conditions, but he obtained simpler conditions. Fourier demands that in $f(x)=0$, neither $f'(x)$ nor $f''(x)$ shall vanish for the interval above referred to. The condition relating to $f'(x)$ is not necessary, as has been shown by Darboux; Mourraille does not give it. Mourraille advances a new rule of his own to determine whether certain roots are distinct, or equal, or imaginary. This is the very rule worked out independently and published with greater detail sixty-three years later by Fourier under the name of

[1] *Histoire de l'académie de Marseille*, par M. J. B. Lautard, 1. partie, Marseille, 1826, pp. 266, 382, 389, 396, 465; 2. partie, 1829, pp. 49, 334. Also *Histoire de Marseille*, par. A. Fabre, t. II, 1829, pp. 409, 496.

"Rule B." Mourraille gives careful consideration to equal roots, and the case of a single root at a point of inflexion, when the curve is concave to the axis of x in its neighborhood, on both sides. It is worthy of remark that Mourraille, like Reyneau before him, avoids all reference to Descartes rule of signs.

As we have already seen, the years 1768 to 1770 were years of great activity in the theory of equations. Lambert, Euler and Lagrange published articles on numerical equations. Of these, the ones bearing on the method of series, will be discussed later. In one paper, Lambert enters upon an elaboration of some of the results reached by Waring[1] giving special attention to the limits of the roots and the solution of the quartic.

The crude mode of approximation published by Stevin, consisting merely of successive trials, appears here and there during the seventeenth and eighteenth centuries. It was given in Philipp Ronayne's Algebra, London, 1717 and 1727, and in John Kersey's Algebra, 1673-74. Kersey's chapter on Stevin's method was reprinted in William Frend's Algebra, London, 1796, pp. 502-513. The first method of approximation explained by Jean Antoine Nicolas de Condorcet (1743-1794) in his article on "Approximation" in the *Encyclopédie méthodique* (about 1784) is substantially the method of Stevin. The only modification introduced by Condorcet is a transformation which multiplies the roots by 10 every time that a new digit in the root is to be found.

We proceed now to the efforts put forth to find roots of equations by the method of series. The earliest mathematician to suggest the method of *recurring series* was Daniel Bernoulli (1700-1782) who in 1728 wrote the *Observationes de seriebus recurrentibus.*[2] In the case of a quartic, bring it into the form $1=ax+bx^2+cx^3+ex^4$, then select arbitrarily

[1] *Beytraege Z. Gebrauche d. Math. u. deren Anwend. Zweyter Theil*, Berlin, 1770, S. 184–249.

[2] *Commentarii Academiae Petropolitanae*, 1728, T. III, pp. 85–100. Cantor III, 643.

four numbers, A, B, C, D, and find a fifth, E, thus, $E=aD+bC+cB+eA$, also a sixth by the same recursion formula, $F=aE+bD+cC+eA$, and so on. If the process be continued to a certain point, and the last two numbers found be designated by M and N, then $x=M\div N$ is an approximate root. Thus, if $1=-2x+5x^2-4x^3+x^4$, then $A=B=C=D=1$ yields $E=0$, $F=2$, $G=-7$, $H=25$, $I=-93$, $K=341$, $L=-1254$. Here $x=K\div L$ is a fairly close approximation, for when substituted in the equation it gives $1=0.999487$. The process is similar for equations of higher degree. Bernoulli gives no proof, but is aware that this process does not necessarily yield results which converge to a root when the equation has equal roots or complex roots.

Leonhard Euler (1707-1783) perfected this method in the 17th chapter of the first volume of his *Introductio in analysin infinitorum*, Lausannae, 1748. By the use of partial fractions and the expansion into infinite series by the method of undetermined coefficients, he arrives at general expressions for the coefficients P and Q, of the nth and $(n+1)$th terms, such that the ratio $Q\div P$ approaches the largest root of the equation, as n increases indefinitely. The results rest on the supposition that there is a real root larger than all other real roots and larger than the moduli of complex roots. He finds, $P=Ap^n+Bq^n+\ldots$, where p, q, . . . are roots of the equations. If p is the largest root, then for very large values of n, P is nearly equal to Ap^n. Similarly Q is nearly equal to Ap^{n+1}; hence the ratio $Q\div P$ is nearly equal to P. By transforming the given equation into another whose roots are the reciprocals of the given equation, the smallest root of the given equation can be found by this process. The idea of considering high powers of other roots negligible in comparison with the like powers of the root which is numerically the largest is due to Newton, who, as we have seen, determined on this principle an upper limit of the roots.

A most interesting variation of the method of recurrent

series which is, however, not generally applicable, failing, for instance, when the second term of the equation is wanting, was given by Euler in his *Algebra*, St. Petersburg, 1770, 2nd part, chap. 16, p. 201. Euler finds for each equation a series of numbers, *a*, *b*, *c*, etc., such that any number divided by its preceding gives an approximation to a root, which is the closer the further the series is continued. By this process the largest root is usually obtained, but no critical study of the conditions under which it is applicable is given by Euler.

This subject of recurrent series is treated by Lagrange in Note VI of his *Résolution des équations numériques*. He gives devices for securing more rapid convergence, and for approximating to *any* real root of an equation, provided one knows in advance the limits which separate that root from the others.

One of the earliest applications of series to equations was made by Brook Taylor[1] in 1717 by expressing the root of a quadratic equation in the form of an infinite series.

A method of determining the roots of cubic equations by infinite series was given in 1838 by Francois Nicole (1683-1758).[2] His prime object was to assist the practical computer, who could not obtain the numerical values of the real roots from the algebraic solution. He derived the infinite series by expanding each of the two radical expressions in the algebraic solution by the binomial formula, and eliminating the imaginary terms by adding the two expansions. This mode of treatment was made easily accessible to mathematicians by Alexis Claude Clairaut (1713-1765) who inserted it in his *Eléments d'algèbre*, Paris, 1746, a popular work which was translated into German in 1752 by C. Mylius.

The values of roots were determined by Thomas Simpson by the reversion of series[3] in 1743, and by infinite series in his *Algebra* of 1745, second edition 1755 (Section XII). We

[1] *Philosophical Transactions*, Vol. 30, pp. 612–622.
[2] *Mem. Acad. Par.*, 1838, pp. 99, 100.
[3] *Math'l Dissertations*, London, 1743, p. 102.

have previously spoken of Courtivron's discussion of the Newton-Raphson process which led him to expressions for the roots in the form of infinite series.

The subject of trinomial equations, which received a very marked attention a century later, was first studied at this time by J. H. Lambert.[1] The value of x in an equation $x^m+px=q$ appears in the form of a rapidly converging infinite series, and Lambert gives the condition of its convergence. Such series were given also by Malfatti.[2]

In a second publication, *Observationes analytiques*,[3] Lambert tells that when he arrived in Berlin in 1764 he communicated to Euler and later to Lagrange his results on trinomial equations, published in 1758, in the Acta Helvetica, whereupon Euler extended them to quadrinomial equations, while Lagrange reached still further generalizations. Euler's paper, *Observationes circa radices aequationum*,[4] leads up to a series giving the largest root of $1=\frac{A}{x}+\frac{B}{x^2}$. By induction he arrives at the corresponding series for $1=\frac{A}{x^\lambda}+\frac{B}{x^\mu}$. Proceeding to quadrinomial and to general equations and following devious paths, Euler arrives at results indicating that any root,—more than that, any power of a root,—may be represented by an infinite series.

The important research by Lagrange, to which Lambert alludes, contains the solution of the equation $\lambda-x+\varphi(x)=0$ (where $\varphi(x)$ is any function) by an infinite series, now known as "Lagrange's reversion formula."[5] In Note XI of his book *Résolution des équations numériques* Lagrange states that his formula yields the root which is numerically the least. Felice

[1] *Acta Helvetica*, Basileae, Vol. III, 1758, pp. 128–168.

[2] *Boncompagni Bull.*, T. IX, p. 469.

[3] *N. mémoires de l'acad. roy. des sciences, année*, 1770, Berlin, 1772, pp. 225–244.

[4] *N. Comm. Petr.* T. XV *pro anno* 1770. Petropoli 1771, pp. 51–74.

[5] "Nouvelle méthode pour résoudre les équations littérales par le moyen des séries" in *Mémoires de Berlin* T. 24, 1770; Lagrange, *Oeuvres* T. III, pp. 5–73. "Sur le probleme de Képler," in the same memoirs, T. 25, 1771; *Oeuvres* T. III, pp. 113–138.

Chio (1813-1871) has shown that this is not always true and has given a theorem in regard to this.[1]

In 1776 Euler completed two more articles on this subject.[2] In the first he speaks in high appreciation of Lambert's expansion in series of the root-values of trinomial equations. In the two articles Euler discusses the representation by series of the roots and of powers of the roots, and endeavors to simplify and clarify a subject which was then still enveloped in considerable mystery. Euler makes no reference to the papers of Lagrange, published a few years before. In a third article written in 1776, but not published until twelve years later,[3] Euler deduces still another series for solving equations, but fails to consider the all important question of its convergence.

In 1794 the subject of trinomial equations demanded the attention of Adam Ehregott Leberecht Hulbe (1768-?) who in a remarkable and much neglected book[4] derives series yielding the roots of $x^m+Qx+R=0$ and $x^m+Qx^{m-1}+R=0$, and pays some attention to the question of convergence.

That the solution of equations by series demanded the attention also of Italian mathematicians is evident from an article[5] of Padre Stanislao Canovai (1740-1811), who refers to Lagrange and Waring and tries to simplify the mode of exposition of their theories. An attempt to find a general solution of equations is that of Pietro Franchini (1768-1837), who was professor of mathematics in Rome, later in Lucques.[6] He derives infinite series for the calculation of the roots, but does not test their convergence.

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[1] *Comptes Rendus*, Paris, 1846, p. 492.

[2] *N. Acta Petr.* IV, 1786, pp. 55–73, pp. 74–95.

[3] *N. Acta Petr.* T. VI, *ad ann.*, 1788. Petropoli, 1790, pp. 16–24.

[4] *Analytische Entdeckungen*, Berlin und Stralsund, 1794, Capitel 4 und 5.

[5] *Atti dell 'accademia delle scienze di Siena detta dé Fisio-Critici*, T. VII, 1794, pp. 29–45.

[6] Franchini, "Sur la résolution des équations d'un degré quelconque," *Mémoires de l'acad. d. scien. de Turin, année*, 1792 a 1800, T. VI. Turin 1801, Pt. II, pp. 115–126.

In 1777 Lagrange wrote to Lorgna[1] that his researches on numerical equations, published in 1767 and 1768 had not received the attention they deserved. In 1798 Lagrange published his work, *De la résolution des équations numériques de tous les degrés*, Paris, an VI, to which we have already made frequent reference. Lagrange sent a copy to Pietro Paoli, with the remark,[2] "It contains my old memoirs on the solution of numerical equations, . . . with numerous notes on these memoirs and other points in the theory of equations. I added these notes to direct the attention of mathematicians to this important subject in analysis which they seem nearly to have abandoned." There is much in the way of historical and critical exposition in these notes. A second edition of this great book appeared in 1808; a third in 1826 with an introductory analysis of the book by Louis Poinsot (1777-1859), first published in 1808 in the *Magasin encyclopédique*. On the subject of the Newton-Raphson method of approximation, Poinsot, who had not seen Mourraille's improvements offers the suggestion that, since this method cannot be used with safety, because the subtangent may yield corrections diverging from the true value of the root, one might draw the chord of the arc whose extremities correspond to the two abscisses which mark the limits of the root sought. As this chord crosses the axis of x at a point between these limits, that point is sure to yield a value closer to the value of the root. Poinsot does not consider the case of equal roots, nor does he suggest an analytical plan for carrying out the computation.

This great book of Lagrange wielded a wide and deep influence upon mathematicians. There are few prominent writers on equations during the early part of the nineteenth century who do not refer to this publication and make numerous extracts from it. The historical and critical notes at

[1] Lagrange, *Oeuvres*, T. XIV, p. 253.

[2] *Memoire della regia accad. di scienze in Modena, Serie III*, T. I, 1898, p. 109.

the end met with especial appreciation not only in France, but also in England, Germany and Italy.

SUMMARY.

1. The finding of a number superior to the largest real root and inferior to the least is taken up by De Baune (1659), Newton (1707), Maclaurin (1748). .

2. The separation of the real roots is studied by Rolle, Waring and Lagrange. The last two use the Protean "equation of the squared differences."

3. Descartes rule of signs discovered, (1637).

4. Criteria for imaginary roots given by Newton, Stirling, Maclaurin, Campbell, De Gua, Waring, Euler, Fontaine, Séjour, Lagrange. Those of Waring and Lagrange alone are at the same time both necessary and sufficient, but they are excessively laborious.

5. Hudde gives test for equal roots, (1659).

6. Vieta extends the process of evolution to the approximation to the roots of affected equations, (1600). His method is used by Dechales and Oughtred; it is slightly improved by Harriot and Wallis, and greatly improved by Newton, (1669), by simplifying the divisor.

7. Raphson's modification of Newton's process now goes by the name of "Newton's method." We shall call it the "Newton-Raphson method." It is re-invented by Wastel and Lambert. Newton's original method is modified by Halley and Taylor. All these methods are insecure. Thomas Simpson first applied the Newton-Raphson process to transcendental equations.

8. Waring outlines process of approximating to imaginary roots by Newton's method.

9. The Newton-Raphson process is made secure by Mourraille, (1768), but his work is overlooked.

10. Method of differences explained by Collins (1669), and De Lagny (1705). It is defective and impractical.

11. Cataldi, (1613), expresses the square root in terms of a continued fraction.

12. Lagrange invents method of solving affected equations by continued fractions (1767), which is general (including imaginary roots), secure and elegant, but tedious in practice.

13. Solutions by recurrent series are developed by Daniel Bernoulli (1728), Euler and Lagrange.

14. Solutions by infinite series are given by De Lagny and Nicole (for cubics), by Lambert, Malfatti and Hulbe for trinomial equations; by Courtivron, Simpson, Euler, Lagrange, Canovai, Franchini for general equations.

15. Lagrange's celebrated work, the *Résolution des équations numériques de tous les degrés* is published in 1798.

GENERAL REMARKS.

With the publication of Lagrange's great book of 1798, containing his own rich researches and a critical summary of the work of other investigators, a brilliant period in the history of the theory of equations is drawing to its close. Seventeenth and eighteenth century mathematicians have grappled with the problem of the solution of numerical equations, wrestled with it, overcome and exhausted it for the time being. The great problems have found a solution. To be sure, the solution may be mainly theoretic; some devices for actual attainment of root-values may be so roundabout and involved as to be prohibitive in practice. But the theory is sufficiently advanced to afford the possibility of approximation to all the roots of algebraic equations with numerical coefficients, whether the roots be equal or unequal, commensurable or incommensurable, real or imaginary.

As we halt between two periods, the query arises, where may we look for the next opening of discovery? On what field will the joy of combat be felt next? Or is all conflict at an end? Has the territory been conquered as fully as it can be? No general *algebraic* solution of higher equations is possible; is the further progress of *approximate* solution stopped by some similar circumstance?

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PART III. MODERN TIMES.

Refinement of old methods. New methods and fuller conques of the imaginary.

1. The Newton-Raphson and Allied Processes.

During the nineteenth century many theoretical studies of the Newton-Raphson method and of allied methods were carried on, especially in France. Inasmuch as the Newton-Raphson method presupposes that a fairly close approximation to a root is known before the method is set in operation, it is evident that the study of it, in its broader aspect, includes the all-important question of the separation of the roots and therefore also the detection of numbers larger (or smaller) than all the real roots of an equation. We find it convenient to group all these researches under the present head.

It is worthy of notice that the method of Vieta which is the grand-parent of the Newton-Raphson process, was, in the early part of the nineteenth century, given a renewal of youth by Heinrich Bauer[1] of Potsdam. That Bauer's procedure is essentially that of Vieta was first pointed out by the Berlin Academy of Sciences to which Bauer had submitted his paper prior to its publication. Vieta's method found a rejuvenescence also in a pamphlet published in 1829 by Egen of Soest in Prussia.[2]

A dissertation on numerical equations was published in Leipzig, in Latin, by Mauricius de Prasse, in two parts.[3] The first part appeared in 1807, the second in 1811. Prasse

[1] *Ueber die allgemeine Entwickelung aller moeglichen Wurzeln der numerischen algebraischen Gleichungen jedes Grades, nach einer neuen Formel.* Von Heinrich Bauer, Potsdam, 1810; second edition, 1825.

[2] Egen, *Ueber die Methoden Zahlengleichungen durch Näherung aufzuloesen.* Elberfeld, 1829. See O. Berger, "Entwickelungsgang der Auflösungstheorie algebraischer Zahlengleichungen" im *Programm des Gymnasiums zu Lemgo fuer das Schuljahr*, 1848-49.

[3] Mauricius de Prasse *De Aequationibus numericis altiorum ordinum commentatio*, I., 1807; II., 1811; Lipsiae.

wrote under the influence of Lagrange, but failed to develop new results.

The discovery of numbers above the greatest root and below the least, continued to command the attention of certain writers. In 1815 Bret, professor at Grenoble, printed three theorems,[1] of which the following has frequently found its way into books on equations: If fractions are formed by giving each fraction a negative coefficient in an equation for its numerator, taken positively, and for its denominator the sum of the positive coefficients preceding it, if moreover unity is added to each fraction thus formed, then the largest number thus obtainable is larger than any root of the equation.

Noteworthy is also the following superior limit, due to Vène:[2] If P is the greatest negative coefficient, and if S be the greatest coefficient among the positive terms which precede the first negative term, then will $P \div S + 1$ be a superior limit to the positive roots of the equation.

The subject of limits was taken up again in 1843 by Thibault[3] who gives two rules for the upper limit of the roots and then proceeds to explain an easy detection of commensurable roots in the case of an absolute term with a large number of factors. Half a century later, in 1892, Fouret says that in works on algebra the rule of Newton on the superior limit of roots is usually given, which says that any value of x which renders $f(x)$ and its derivatives of the same sign, is such an upper limit. In place of the ordinary procedure of substituting $-x$ for x, in order to find an inferior limit, Fouret suggests the following in completion of Newton's rule:[4] The value of x, positive or negative, which, when substituted in $f(x)$ and its successive derivatives, gives results alternatively positive and negative, is an inferior limit. He

[1] *Annales de mathématiques pures et appliques* (Gergonne), T. 6, 1815, pp. 112-122.

[2] *Mémoires de l'académie de Bruxelles*, 1822, 1824.

[3] *Nouvelles Annales de math.*, T. II., 1843, pp. 517-527.

[4] *Bulletin de la société math. de France*, T. 20, 1892, pp. 4-6.

also gives a rule for the inferior limit, suggested by one of Thibault's rules for the superior limit.[1] Articles on superior and inferior limits were also written by Mourgues,[2] by Gislard Vanson,[3] and by Laguerre, as we shall see later.

A test for the absence of all roots from a given interval was given by Bellavitis in 1846 which is of practical value, notwithstanding the fact that it is quite involved.[4]

Of importance in the detection of imaginary roots is the memoir, published in 1807 in Paris by the French physician F. D. Budan, under the title *Nouvelle méthode pour la résolution des équations numériques.* It contained results reached by him as early as 1803. Budan gives (p. 26) the theorem, deduced from Descartes' Rule of Signs, that an equation whose roots are all real cannot have as many as n roots between zero and a positive number p, unless the equation has at least n more variations in sign than the equation obtained by writing $x-p$ for x. The enunciation of this theorem is followed by the remark that "we have strong reasons for the belief" that this proposition is "applicable to any equation," whose roots are not necessarily all real. What is nowadays known as "Budan's theorem" is the theorem given above, generalized for "any equation." From these statements it follows that in 1807 Budan had not only not proved the generalized theorem, but had not yet satisfied himself that it is really true. This fact is of importance in the consideration of the question of priority between Fourier and Budan. In 1811 Budan read a paper before la première classe de l' Institut, in which he aimed to give a rigorous demonstration of the general theorem known by his name. The paper was referred to Lagrange and Legendre, who reported that the proof lacked certain developments which could, however, be easily supplied, that the theorem was new and useful, though

[1] *Loc. cit.*, p. 37.
[2] *N. Ann. Terq.*, 1850, Vol. 9, p. 108-115.
[3] *N. Ann. Terq.*, 1852, Vol. XI, p. 61, 107.
[4] *Memorie dell' I. R. Istituto Veneto di scienze, etc.*, Vol. III., 1846, §34; also 1860, p. 183.

not always capable of indicating the limits of each of the real positive roots, that it can be applied to negative roots by writing $-x$ for x, that it is an "extension of Descartes' Rule." In 1822 Budan's pamphlet of 1807 was re-published, along with his proof of 1811, Lagrange and Legendre's report on the same, and some additional notes by Budan. We shall see that Budan's theorem is nearly identical in principle, although different in statement, to a theorem of Fourier which was printed in 1820, although discovered by Fourier much earlier.

Legendre[1] set up a simple upper limit for the positive real roots. He applied the Newton-Raphson process to finding the greatest root φ of a "fonction omale" (a function either steadily increasing or steadily decreasing while x is increasing from zero.) After depressing the degree of the equation, through division by $x-\varphi$, he repeats the process with the new equation. As a second method, Legendre breaks an equation up into two simple "omale" functions and finds the intersection of their graphs. Finally, Legendre proceeds to the determination of imaginary roots, using here the integral calculus. The search of a root is reduced by him to the solution of a binomial equation.

Legendre's research on the "fonction omale" was discussed by Évariste Galois,[2] who suggests a substitute for one of the processes indicated by Legendre.

In 1818 Bérard of Nismes published a pamphlet, entitled *Méthodes nouvelles pour déterminer les racines des équations numériques*, which lays stress on geometric and mechanical aids to computation, later perfected by Lalande. Bérard approximates to the roots of equations by Newton's method which he endeavors to render sure by certain new modes of verification first published by him in 1810 in his *Opuscules*

[1] *Mémoires d. l'acad. r. d. sciences de l'Institut de France*, Année 1816, I, page *x*; *Théorie des nombres*, Paris, 1830, T. II., pp. 396-463.

[2] *Bulletin d. scien. math. de M. Férussac*, T. 13, 1830, p. 413.

mathématiques.[1] The theory is vitiated by the use of a false theorem, advanced by him, on the number of real and imaginary roots.

The subject of imaginary roots continued to command the attention of mathematicians with ever increasing interest. Not only in France, but also in Italy and in Germany we meet with serious attempts to conquer this field.

In a paper[2] of 1823 an Italian investigator, Geminiano Poletti, passes in critical review the methods of finding imaginary roots, namely, Lagrange's method by the equation of the squared differences of the roots, Euler's method of forming two equations by equating the reals and the imaginaries, and Legendre's modification of this. Poletti then proceeds to his own method of forming two equations, the first of which contains the real parts of complex roots and the other the squares of the imaginary parts, and then solving each by Budan's process.

The solution of numerical equations was studied with predilection by Joseph Fourier (1768-1830). He made it the subject of his earliest researches. "About the close of the year 1789," says Arago, "Fourier repaired to Paris and read before the Academy of Sciences a memoir on the resolution of numerical equations of all degrees. This work of his early youth our colleague, so to speak, never lost sight of. He explained it at Paris to the pupils of the Polytechnic School; he developed it upon the banks of the Nile in presence of the Institute of Egypt; at Grenoble, from the year 1802, it was his favorite subject of conversation with the professors of the Central School and of the Faculty of Sciences; this finally contained the elements of the work which Fourier was engaged in seeing through the press when death put an end to his career."[3]

[1] Cauchy, *Oeuvres complètes*, 1re série, T. V., Paris, 1895, p. 501.

[2] "Nuovo metodo per determinare le radici immaginarie, etc." di G. Poletti, *M. Accad. Torino*, 1826, T. XXX., pp. 49-80; 1831 T. XXXV.

[3] *F. Arago, Biographies of Distinguished Scientific Men.* First Series. Boston, 1859, p. 380. (Joseph Fourier).

The interest of Fourier lay almost entirely in those parts of mathematics which admit of direct application to the physical sciences. His *Théorie analytique de la chaleur* (1822) marks an epoch in the history of mathematical physics; Lord Kelvin has repeatedly referred to the inspiration he received as a young man from this great work. No doubt the solution of numerical equations appealed to Fourier, because of the practical nature of the subject. Strangely enough he published very little on this subject until the close of his life. His *Analyse des équations déterminées*[1] was intended to embody all his results on the theory of equations, but Fourier saw before his death only the first four pages of this work in print. The work was planned to contain seven books, but after his decease the introduction, a general outline of the results to be established and the first two books were found to be about the only parts ready for print. Of the second book, articles XXIV to XXX were only sketched, and Claude Navier, who saw the publication through the press, elaborated this part from Fourier's manuscript notes.

Fourier had the misfortune of being anticipated in two of his important results. His improvements on Newton's method of approximation, rendering the process applicable without the possibility of failure, have been supposed to have no rival claimant. But we have pointed out that over half a century before the publication of Fourier's work, one of his countrymen by the name of Mourraille, had reached the same results by the very same geometrical methods. Then again Fourier's method of settling the question whether two roots near the border line of equality are really equal, or perhaps slightly different, or even imaginary, had been worked out by Mourraille in the same manner, though not so carefully and fully.

[1]This work is now quite rare: it is not included in the *Oeuvres de Fourier*, brought out by Gaston Darboux in two volumes, Vol. I., 1888; Vol. II., 1890. In 1902 the *Analyse des équations déterminées* was translated into German by Alfred Loewy and brought out, with notes, as *Ostwald's Klassiker*, Nr. 127.

Much confusion has prevailed as to the right of priority between Fourier and Budan respecting the theorem on the number of real roots between two chosen limits. On this point Arago expresses himself as follows: "I doubt whether it were possible to cite a single scientific discovery of any importance which has not excited discussions of priority. The new method of Fourier for solving numerical equations is in this respect amply comprised within the common law. We ought, however, to acknowledge that the theorem which serves as the basis of this method, was first published by M. Budan; that according to a rule which the principal Academies of Europe have solemnly sanctioned, and from which the historian of the sciences dares not deviate without falling into arbitrary assumptions and confusion, M. Budan ought to be considered as the inventor. I will assert with equal assurance that it would be impossible to refuse to Fourier the merit of having attained the same object by his own efforts. I even regret that, in order to establish rights which nobody has contested, he deemed it necessary to have recourse to the certificates of early pupils of the Polytechnic School, or Professors of the University."[1]

But Arago's dictum has not been accepted as final. Is the publicity rule which Arago follows to be accepted as equitable in this case? There is no need of answering this question. If it is so accepted, then the query still remains: can Budan's tract of 1807 be considered a "publication" of "Budan's theorem"? As previously pointed out, not only did Budan not prove his *general* theorem in 1807, but he actually expressed uncertainty as to its validity. In view of this fact it would seem as if Budan's publication of 1822 were the only one that could be considered in settling this question. Fourier first had his theorem and its proof printed in 1820,[2] and therefore is entitled to priority by the fact of

[1] *F. Arago, Biographies of Distinguished Scientific Men*, First Series, Boston, 1859, p. 383.

[2] *Le Bulletin des sciences par la Société Philomatique de Paris*, année 1820, p. 156, 181.

previous publication. But if the publicity rule named by Arago is in this case not accepted as equitable, then the argument is still in favor of Fourier, for it is disputed by no one that he taught his theorem to pupils in the Polytechnic School in 1796, 1797 and 1803, while Budan presented his earliest exposition before the Institute in 1803.

Proceeding to the study of Fourier's researches we begin with the paramount problem of determining the number of real roots between given limits and of ascertaining how many of these are real and how many are complex. To accomplish these ends he established his well-known theorem and a rule —"Theorem A" and "Rule B"—as he called them. The theorem is usually called "Fourier's Theorem."

Fourier indicates the equation of the m^{th} degree by $X=0$, the successive derivatives of X by X', X'', . . . $X^{(m)}$. Arranging these in the order

$$X^{(m)}, X^{(m-1)}, \ldots X''', X'', X', X$$

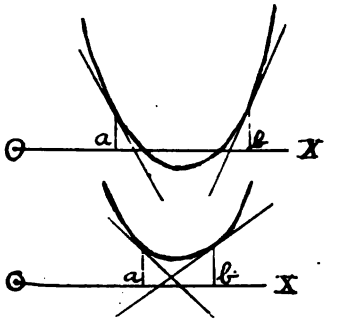
and designating the series by (φ), when φ is written for x, he states on page 27 his Theorem A as follows: "If the number of variations in sign of the series (a) exceeds that of series (b) by a difference i, one must seek i roots between a and b."

The correctness of this theorem is set forth with a clearness and profuseness which is characteristic of the entire work. He shows on page 101 that Descartes' Rule of Signs is a special case of Theorem A. The part of this rule which says that "the given equation cannot have more real negative roots than there are permanences of signs in the series of coefficients" applies only to equations in which no terms are missing, but Fourier for once fails to mention the necessary restriction.

Fourier devotes much space in developing criteria for complex roots and he sets up a mode of procedure which is called "Rule B" at the beginning of his treatise, but which is nowhere stated in concise form suitable for quotation. He explains[1] that $x-\frac{f(x)}{f'(x)}$ is the expression for the intercept of

[1] *Analyse*, p. 121.

the tangent line on the axis of X, that this intercept is always numerically greater for $x=b$ than for $x=a$ when the roots are real and the curve cuts the axis of X as in our first figure. Here, taking the numerical values of $f(b)$, $f'(b)$, $f(a)$, $f'(a)$, he derives for real roots,



$$\text{I.}\quad \frac{f(b)}{f'(b)}+\frac{f(a)}{-f'(a)}<b-a.$$

If this inequality is not satisfied, our second figure shows that the two roots must be complex.[1]

Next we explain Fourier's "indices." Substitute a and then b in $f(x)$ and its m derivatives, and observe the signs of the results. Arrange the work as follows and suppose the signs to be as here indicated:

	$f^m(x), f^{m-1}(x), \ldots f^n(x) \ldots f''(x), f'(x), f(x)$						
(a)	$+$	$-$	$\ldots$	$+$	$\ldots$	$-$	$+$	$+$
	0	0	$\ldots$	1	$\ldots$	2	2	3
(b)	$+$	$-$	$\ldots$	$-$	$\ldots$	$-$	$+$	$-$

The numbers 0, 0, 1, 2, 2, 3, are the "indices." They are determined as follows: By Theorem A we see that $f^{m-1}(x)=0$ has no roots between a and b; write 0 below this function. Do the same for all other functions. Thus, if $f(x)$ and all its derivatives have three more variations in sign for $x=a$ than for $x=b$, write 3 below $f(x)$.

Next consider a case where $f(x)$ has the index 2 and $f''(x)$ has the index 0. Then the three right hand indices are shown to be 0, 1, 2. If condition I, given above, is not satisfied, it is certain that two roots of $f(x)=0$ are complex. If it is satisfied, and $f(x)=0$ has no double root between the limits a and b, select a number c between a and b. If this does not separate the two roots and if $f'(a)$ and $f'(c)$ have opposite signs,

[1] In Serret's *Cours d'algèbre supérieure*, Vol. I., Article 143, Fourier's geometric process is replaced by an analytic deduction.

the two roots, if real, lie between a and c, and we make the same tests for these limits that we made for a and b. Fourier asserts, without offering formal proof, that, continuing this process, we can surely determine whether the two roots are real or complex.

Dropping the restriction that the index of $f''(x)$ is zero, Fourier tests the nature of the two or more roots, which by Theorem A may lie between a and b. He examines the indices from right to left until the index 1 is reached. Let the corresponding function be $f^n(x)$. By Theorem A, $f^n(x) = 0$, has only one root between a and b; this is real. It is shown that the index to the right of 1 must be 2. If the index to the left of 1 is not 0, it can be made 0 by narrowing the limits from a—b to a'—b'. Suppose now that the three indices in question are 0, 1, 2, and that no index 1 has appeared during the change of limits farther to the right in the series. In this case, and this only need we look for complex roots. In other cases, where the indices 0, 1, 2, do not appear, Fourier's process affects a separation of the roots. The indices 0, 1, 2, show that between a' and b', $f^{n+1}(x) = 0$ has no roots, and $f^n(x) = 0$ has one real root, while $f^{n-1}(x) = 0$ cannot have more than two roots. If $f^{n-1}(x) = 0$ has two real roots, then the root φ of $f^n(x) = 0$ must yield opposite signs for $f^{n+1}(\varphi)$ and $f^{n-1}(\varphi)$; otherwise the signs are alike. If $f^{n-1}(x) = 0$ has two complex roots, it follows that $f(x) = 0$ has two also. In proceeding to separate the remaining roots between a and b, diminish each of the indices to the right of $f^n(x)$ by 2 and proceed with the new series of indices as before.

By this process, which is not as difficult in practice as might be inferred from our statement of it, Fourier separated the real roots and determined the number of complex roots. He felt that he had made a real advance over Lagrange. Lagrange had disposed of this question by computing the least difference between successive roots. As this computation is usually exceedingly long and tedious, it is of little value in practice.

One point in Fourier's exposition deserves closer attention. Fourier says[1] that, if two roots which, according to Theorem A, are to be looked for between a and b are "lost" in the interval, it is because some derivative, say $f^n(x)$, vanishes for a value φ that lies between a and b, while its two neighboring derivatives assume like signs for $x=\varphi$. "This is the general character of imaginary roots, that the series of signs loses in this case two variations. If the middle function vanishes, then φ is a critical value, which corresponds to a pair of imaginary roots." This statement was commented upon by Gauss[2] who says: "Fourier calls such places critical; each such critical place insures accordingly the loss of two real roots; when, however, Fourier at the same time asserts that two roots thus dropping out become imaginary, we cannot admit his mode of expression, for it may easily give rise to misconception. To be sure, it is true that the equation $X=0$ contains altogether exactly as many pairs of imaginary roots as there are such critical places; but the values of the imaginary roots are as definite as those of the real, and the above mode of expression can easily be so interpreted as if to each particular gap there belonged a definite pair of imaginary roots, which is not only not proved by Fourier, but must remain doubtful until deeper researches place this interesting point in a clear light." This question still awaits the deeper research.

In the second book of the *Analyse des équations déterminées* Fourier proceeds to explain how to effect approximations to the roots. The method of Horner, published in England twelve years earlier, was unknown to him. He devoted himself to the perfection of Newton's method and he believed that he was the first to show how it could be made to yield results always converging to the required root. Let the roots be distinct and separated. Assume that one root lies between a and b. If the three right hand indices are not 0, 0, 1, find

[1] *Analyse*, p. 28.
[2] *Gauss, Ges. Werke*, Vol. III., p. 120.

closer limits so that the indices do become 0, 0, 1.[1] When this is so, the two equations $f''(x)=0$ and $f'(x)=0$ have no roots between the limits. Hence the graph of $f(x)=0$ has no point of inflexion and no tangent parallel to the X axis between the last found limits. Next, care must be exercised to begin the approximation with that limit which gives $f(x)$ and $f''(x)$ the same signs; that is, the limit from which the part of the graph between the limits appears convex. The use of the other limit may result in failure to approximate to the required root. If the limit to be chosen is φ, then $\varphi'=\varphi-\frac{f(\varphi)}{f'(\varphi)}$ is a value closer to the root. In the case of equal roots, find the factor common to $f(x)$ and $f'(x)$. Equating this factor to zero and solving reveals the equal roots.

Fourier names one condition for insuring success in the approximation which Mourraille in 1768 had not given, namely the condition that $f'(x)$ shall have no root lying between the limits finally chosen. It was G. Darboux[2] who proved that this condition is not necessary, that the approximation can always be carried on safely, when $f(x)=0$ has only one real root between the limits, if $f''(x)=0$ does not change its sign between these limits, and the computation begins with the limit which gives to $f(x)$ and $f''(x)$ the same signs.

Fourier was not merely a theorist; he was interested in practical computation as well. For that reason he did not stop after having shown how the roots can always be safely obtained, but set to himself three further tasks:[3] 1. To formulate a process of division which avoids all unnecessary computation of digits; 2. To carry out the successive substitutions in computing the root, so that no part of the operation is repeated. 3. To determine the degree of approximation at each step. The details worked out by Fourier are too

[1] *Analyse*, p. 180.

[2] "Sur la méthode d'approximation de Newton," *Nouv. Annales de math.*, 2me série, T. VIII., pp. 17-27, 1869.

[3] *Analyse*, p. 187.

specialized for ordinary instruction in schools. His *division ordonée* is given by several modern writers.[1]

Fourier proceeds from the Newton-Raphson method—an approximation of the first order—to the elucidation of the principles of approximation of the second order.[2] Mention will be made later of several other interesting matters touched upon by Fourier, such as the solution of transcendental equations[3] developed later by M. A. Stern and others, and the solution of equations by the method of iteration[4] and by recurrent series.[5] This last method, first suggested by Daniel Bernoulli and Euler, and later extended somewhat by Lagrange, was still further extended by Fourier, so as to apply to imaginary roots, but unfortunately the results were never made public. Fourier died before the results were put in shape for publication.

Even before the publication of Fourier's great work on numerical equations there appeared a short article on imaginary roots which far surpassed in beauty that which Fourier had offered on this subject. We refer to the classic theorem of Charles Sturm (1803-1855). De Morgan has truly said that this theorem "is the complete *theoretical* solution of a difficulty upon which energies of every order have been employed since the time of Descartes." The theorem was first published, without proof, in 1829.[6] Sturm explains in that article that he had enjoyed the privilege of reading Fourier's researches while they were still in manuscript and that his own discovery was the result of the close study of the principles set forth by Fourier. The limits imposed upon this monograph do not permit us to enter upon the details of the

[1] J. Lüroth's *Vorlesungen ueber numerisches Rechnen*, Leipzig, 1900, p. 49, 51, takes up Fourier's *division ordonée* and makes some corrections on it. It is also explained in O. Biermann's *Vorlesungen ueber mathematische Näherungsmethoden*, Braunschweig, 1905, pp. 18-22.

[2] *Analyse*, p. 218.

[3] *Analyse*, p. 59.

[4] *Analyse*, p. 40.

[5] *Analyse*, p. 68-72.

[6] *Bulletin des sciences par Férussac*, Sec. 1, T. II., 1829.

history of Sturm's theorem, nor to attempt to discuss the profound researches in connection with it that have been carried on by Sylvester, Hermit and others.[1] Proofs of Sturm's theorem were given in 1830 by v. Ettinghausen,[2] in 1832 in Choquet and Mayer's Algebra, and in 1835 by Sturm himself.[3]

Means for determining with certainty the number of real and imaginary roots of numerical equations with real coefficients were invented by the mathematicians of the eighteenth century and by Fourier. But the devices used by them were crude *rules* rather than *theorems*. It is here that Sturm made his great advance. His theorem was a great contribution to the *theory* of equations; however it brought about no revolution in the methods pursued by the practical computer.

In the second article on his own theorem, Sturm points out how the theorem may be utilized in the approximation to roots. By the theorem of Sturm one can ascertain the number of complex roots of an equation, but not their location. That limitation offered an opportunity for further investigation. This was accomplished in a brilliant research

[1]For the history of Sturm's theorem see *Nouvelles Annales de Mathématiques*, (2) Vol. VI., 1867, pp. 238, 428; Sylvester's Presidential Address to the Mathematical and Physical Section of the British Association at Exeter, 1869, reprinted in Sylvester's *Laws of Verse*, 1870, p. 115; Nöther's Biography of Sylvester in *Mathematische Annalen*, Vol. 50, 1898, p. 139. Duhamel and Sylvester both state that they received their information from Sturm directly, by word of mouth. Yet the two statements of the mode of discovery do not seem to agree. According to Sylvester, the theorem "stared him (Sturm) in the face in the midst of some mechanical investigations connected with the motion of compound pendulums." According to Duhamel, the discovery was not the result of observation, but of a well-ordered line of thought as to the kind of function that would meet the requirements. Perhaps both statements are correct, but represent two different stages in the evolution of the discovery in Sturm's mind. How Sturm came to think of changing the signs of the remainders in the Euclidean division has never been satisfactorily brought to light.

[2]*Wiener Zeitschrift fuer Math. u. Phys.*, Vol. 7, reprinted in *Crelle's Journal*, Vol. 13, 1835, p. 119.

[3]*Mémoires présentes par divers savans à l'Académie royale des sciences de l'Institut de France*, T. 6, Paris, 1835, pp. 271-318. A German translation of this has been brought out by A. Loewy in *Ostwald's Klassiker* No. 143, Leipzig, 1904.

by another great Frenchman, Augustin-Louis Cauchy (1789-1857). He discovered a general theorem which reveals the number of roots, whether real or complex, which lie within a given contour. This theorem makes heavier demands on the mathematical attainments of the reader, and for that reason did not attain the celebrity of Sturm's theorem. But it enlisted the lively interest of men like Sturm, Liouville and Moigno, who endeavored to throw it into a form more readily understood. Cauchy's first announcement of his proposition was made in 1831, in a memoir presented to the Academy of Turin.[1] At that time Cauchy expounded the theorem with the aid of the Integral Calculus, but in 1837 he published in the *Journal de l'école polytechnique*, Vol. 15, p. 176, a memoir in which he dispensed with the Integral Calculus and based the theorem on the theory of indices of functions.

Cauchy's theorem enables one to decide how many equal or distinct imaginary roots are such that their real parts lie between a and b, and their imaginary parts lie between φ and μ. This test has enjoyed considerable popularity. For instance, it was given by J. Dienger in his *Theorie und Auflösung der höheren Gleichungen*, Stuttgart, 1866 (p. 66), by De Morgan in his *Trigonometry and Double Algebra*, London, 1849 (p. 141) and in the *Penny Cyclopaedia*, article "Theory of Equations," by Todhunter in his *Theory of Equations*, London, 1880 (p. 231). An article which connects with the theorem of Cauchy was written in 1882 by Thomas Bond Sprague,[2] entitled, "On the nature of the curves whose intersections give the imaginary roots of an algebraic equation."

While the methods of separating the roots worked out by Fourier and Sturm apply only to algebraic equations, theorems applicable to more general types were published in Berlin by E. H. Dirksen in 1835.[3]

[1] C. A. Valson, *La vie et les travaux du Baron Cauchy*, T. II., Paris, 1868, p. 84.

[2] *Trans. of the Royal Soc. of Edinburgh*, Vol. 30, part II., pp. 467-480.

[3] "Ueber die Trennung der reellen Wurzeln reeller numerischer Gleichungen etc." in *Abhandl. d. Akad. z. Berlin fuer* 1835; besonders abgedruckt in Berlin, 1837.

Special practical rules for the separation of the real roots of the third, fourth and fifth degrees were suggested in 1867 by J. Rouget.[1]

A remarkable article was published in 1826 by G. Dandelin,[2] then of the University of Liège. After a discussion of the limits of a root, the author proceeds to a study of the Newton-Raphson method of approximation, and is led to the establishment of the conditions under which the method can be used with security. Dandelin had no knowledge of the work of Mourraille or Fourier, and gave a geometric discussion that is less exhaustive but more concise than that of Mourraille. As Fourier's researches on this point were first published in 1818, Dandelin must go on record as having been anticipated in his improvement of the Newton-Raphson process by two men, Mourraille and Fourier. Like Mourraille Dandelin succeeds in the establishment of sufficient conditions for the safe use of the Newton-Raphson formula which are simpler than the conditions of Fourier. If the given equation is $f(x)=0$, and b an approximate root-value, then Dandelin simply insists that $f(b) \cdot f''(b)>0$ and that $f''(x)$ shall not vanish in the interval between which the root lies. Fourier's additional limitation that $f'(x)$ shall not vanish in the interval is not given. We are led to infer by a remark of Dandelin that he was induced to investigate this subject by Lagrange's belief that it was not possible to set up *a priori* conditions.

Fourier's book of 1831 possessed elements of popularity in its elegant style of exposition as well as in the novelties of its contents. Everywhere it met with almost instantaneous appreciation. In England, authors of text-books like R. Stevenson[3] and R. Murphy[4] gave expositions of Fourier's

[1] *Règles pratiques pour opérer la séparation immédiate des racines réelles*, Paris, 1867.

[2] *Nouveaux mémoires de l'académie roy. d. scien. et bell. de Bruxelles*, T. 3, 1826, pp. 7-71; See also *Correspondance math. et phys.* Gand, T. II., 1826, p. 48.

[3] *Algebraic Equations*, Cambridge, 2nd Edition, 1835.

[4] *Algebraical Equations*, London, 1839.

results at a time when they had not yet heard of the earlier researches of their own countryman, W. G. Horner. In Germany, M. W. Drobisch[1] as early as 1834 explained the theories of the illustrious Frenchman, while Crelle in Berlin inserted in his *Journal*, Vol. 13, 1835, p. 119, a valuable review not only of Fourier, but also of Sturm, and Grunert published an account of Fourier in the first volume of his *Archiv* (1841). In 1837 J. A. Eytelwein brought out in Berlin a monograph on numerical equations, which gives an exposition of Fourier and Sturm.[2] We shall see that immediately after the publication of Fourier's great work of 1831, much ingenuity was exercised by Stern of Göttingen in restoring and extending some of Fourier's deductions.

It was to be expected that the weak points in the theories of Fourier would be exposed to a clearer light and that attempts would be made to remedy them. In England this was done by Murphy and particularly by J. R. Young.

J. R. Young prepared two books on numerical equations: An introductory volume on the *Analysis and Solution of Cubic and Biquadratic Equations*, London, 1842, and *Theory and Solution of Algebraical Equations*, London, 1835, second edition 1843. In these works he criticized Fourier and Sturm on the following points:

(1) Fourier depends upon the method of division for the determination of equal roots—a method which involves much labor, except in very simple examples.

(2) The separation of roots that lie so close together as to have four or five leading figures in common, is delayed in Fourier's process to so remote a step that the patience of the computer is exhausted before reaching it. In the same way the recognition of imaginary roots by Fourier's process is exceedingly tedious when the roots are in the peculiar pre-

[1] *Grundzuege der Lehre von d. hoeh. num. Gleichungen*, Leipzig, 1834.

[2] *Anweisung z. Aufl. d. hoeh. num. Gleichungen*, Berlin, 1837.

dicament of being rendered real by very minute change in value of the absolute term.

(3) While the method of Sturm has the merit of being the only one which treats the analysis of the roots of an equation as a problem perfectly independent of the actual development of roots, it becomes very laborious for equations higher than the fourth degree.

J. R. Young succeeded in reducing the labor in the application of Fourier's processes to such an extent that he preferred them to that of Sturm, in practical work. In many cases he succeeded in shortening the work of testing for two equal roots of $Ax^n+Bx^{n-1}+ \ . \ . \ . \ +Mx+N=0$ by the observation that for two equal roots (and two only), M and N must have a common factor a, and N must be divisible by the square of this factor; likewise A and B must have a common factor (b), and A must be divisible by the square of that factor.[1] If these conditions are satisfied and if $a \div b$ is a root, it is a double root. Young shortened Fourier's process in other respects by making it and the one of Horner mutually subservient. He showed that the analysis of Fourier may be expedited by the method of approximation of Horner, while the uncertainties which occasionally accompany the method of Horner (as the author originally expounded it) may always be removed by the rules and tests of Fourier. No doubt some of the work of Young grew out of the study of examples publicly proposed for solution by James Lockhart. Those examples were equations of the fifth and sixth degree with roots coinciding in some cases to six decimal places. He explained a method of constructing equations with nearly equal roots.[2]

Connecting with the ideas of Waring, Lagrange and Cauchy, Phragmén shows how to determine the presence of equal roots without resorting to the tedious operations by

[1]These same conditions were afterwards worked out by C. H. Schnuse in his *Theorie und Aufloesung der . . . Gleichungen*, 1850, p. 132.

[2]The Mathematician, Vol. I., 1845, p. 165.

the method of the Euclidean greatest common divisor.[1] The same idea is pursued by G. Janni.[2] C. Runge remarks that, in the practical operation of finding the Sturmian functions, the method of the greatest common divisor may usually be simplified by computing the coefficients only approximately, as can be done by the slide rule.[3]

Perhaps the ablest worker in the restoration and extension of the researches given in Fourier's exposé synoptique in bare outline, was Moritz Abraham Stern (1807-1894), of Göttingen. His investigations connect with those of Fourier and Lagrange. His papers on solution by recurrent series will be referred to later. In 1837 the Danish Academy of Sciences demanded a method of resolving transcendental equations, and in 1841 this Academy crowned the memoir on this subject submitted by Stern. He accomplished his resolution by extending to transcendental equations the method given by Fourier for algebraic equations. A plan for such an extension had been indicated by Fourier himself. As the Newton-Raphson process of approximation had been applied to the finding of real roots of transcendental equations long before Fourier, the efforts of Stern were concentrated mainly upon the extension of Fourier's plan for separating and locating the roots of algebraic equations and upon a closer study of imaginary roots. When viewed from the standpoint of the modern theory of functions, the statements of Fourier and Stern on transcendental equations lack accuracy of limitation.

A paper which connects partly with Fourier's researches and partly with the work of J. R. Young and Lockhart in England, was prepared by R. Lobatto, professor at the Royal Academy of Delft.[4] Lobatto wrote on a special class of cubic

[1] *Stockh. Oefv.* Vol. 49, 1892, pp. 179-188; *Jahrbuch ue. d. Fortschr. der Math.*, Vol. 24, 1892, p. 92.

[2] *Rendiconti dell'accademia d. scienze fisiche e math.*, Vol. 17, pp. 138-141.

[3] *Encyclopaedie d. Math. Wiss.*, 1. Bd., Leipzig, 1898-1904, p. 404.

[4] *Journ. d. mathématiques pures et appliquées* (Liouville), T. IX., 1844, pp. 177-190.

equations and also gave criteria for imaginary roots between given limits, in amplification of those of Fourier.[1] This paper was an analytic elaboration of a geometric article published by him at the Hague in 1843.[2]

Great interest in the theory of equations was displayed at different times by the great French mathematician, Augustin Louis Cauchy. In 1826 he showed in his *Analyse Algébrique*, Note III, that a limit inferior to the least difference between the real roots of an equation may be found more simply than by Waring's and Lagrange's equation of the squared differences of the roots, by considering merely the product of all the differences of the roots. But even this improved process failed to meet the practical needs; it too was somewhat laborious and it yielded a value for the limit usually very much smaller than necessary and convenient. The subject of numerical equations again received attention in his *Exercices de mathématiques*, in chapters which were also published separately under the title *Mémoire sur la résolution des équations numériques et sur la théorie de l'élimination*, Paris, 1829. Cauchy simplifies here the computation of a limit inferior to the least difference between the real roots. Thereby he determines the number of real and of imaginary roots and also arrives at a method of approximation to any root, whether real or imaginary. Had Cauchy been familiar with the researches of Ruffini and Horner he would hardly have been able to claim superiority for his own method. More nearly approaching practical needs was Cauchy's paper of 1837, a *Mémoire sur une méthode générale pour la détermination des racines réelles des équations algébriques ou meme transcendantes.*[3] In 1839 this method was made accessible to German readers in an elementary exposition by Franz Seraphin Mozhnik.[4]

[1] *Loc. cit.* T. IX., pp., 295-309.

[2] Lobatto, *Recherches sur la distinction des racines réelles et imaginaires dans les équations numériques*, etc.

[3] *Comptes rendus*, T. V., p. 357.

[4] *Theorie der numerischen Gleichungen mit einer Unbekannten*, Wien, 1839.

Cauchy treats the problem from a general point of view and shows how from given limits of a root, a pair of closer limits may be obtained. He distinguishes between linear modes of approach, requiring the solution of a linear auxiliary equation, and a quadratic mode of approach, depending upon a quadratic auxiliary equation. The Newton-Raphson method of approximation appears as a special case of Cauchy's linear mode of approximation. A point of superiority of Cauchy's method over the Newton-Raphson method is that it does not require so accurate a starting value. In fact it succeeds surely, though perhaps very slowly, no matter how far apart the limits are. Moreover, Cauchy's method reveals with certainty the absence of real roots in a given interval. One sees that this method has the qualities about it which are of the chief interest to a theoretical mathematician. The failure of Cauchy's procedure to attain popularity is probably its lack of simplicity as compared with the Newton-Raphson and the Horner methods, even in the simplified exposition of it given by Cauchy in 1840.[1]

In the endeavor to generalize methods it was to be expected that the Newton-Raphson process would be extended, if possible, to the finding of imaginary roots. Newton's method proper had been thus extended by Waring and also by Thomas Simpson. The procedure of the latter is set forth by Murphy in his *Algebraical Equations*, 1839, p. 124. The Newton-Raphson method was examined with this as one of its goals by Cauchy in an article[2] which surpasses in interest most of the numberless commentaries, modifications and extensions of this method. Cauchy extends it to the case of imaginary coefficients and imaginary roots by the operation with moduli in the place of the real quantities.

In 1879 A. Cayley makes an "Application of the Newton-Fourier method to an imaginary root of an equation,"[3] show-

[1] *Comptes Rendus*, T. XI., p. 829.
[2] *Comptes Rendus*, T. 29, 1849, pp. 250-257.
[3] *Quart. Jour. of Math.*, Vol. 16, 1879, pp. 179-186.

ing that if a is an approximate root of $x^2=n^2$, where n^2 is a given imaginary quantity, then $a_1=(a^2+n^2)\div 2a$ is a closer approximate value if *mod.* $(a-n)<\frac{2}{3}$ *mod.* n. He also investigated the conditions under which the Newton-Raphson formula of approximation works safely when the root sought is imaginary, but he encounters difficulties in the actual application to equations of degrees higher than the second.[1]

Remarkable advances in the theory and solution of equations have been made by Edmond Nicolas Laguerre (1834-1886).[2] We have already mentioned his new proof of Descartes' rule of signs and his extension of it to polynomials with fractional or incommensurable exponents, and also to infinite series. If the variations in the series P, $P+Q$, $P+Q+R$, $P+Q+R+S$ . . . are called the number of *alternances* of the series $P+Q+R+S+$ . . . , then the consideration of these alternances leads to important generalizations. For instance, if the polynomial $Ax^{\varphi}+Bx^{\beta}+$ . . . $+Lx^{\lambda}$, is arranged according to the ascending powers of x, the exponents being real but commensurable or incommensurable, then the number of positive roots less than a is equal to the number of alternances of $Aa^{\varphi}+Ba^{\beta}+$ . . . $+La^{\lambda}$, or less by an even number. Laguerre is led to a method entirely different from those of Waring, Lagrange and Sturm for the determination of the exact number of positive roots of an equation. Unfortunately it is hardly less complicated than Sturm's. Laguerre's expression for the superior limits of the roots was discussed by E. Lucas, L. Levy, Ch. Vénard, Candèze and H. Laurent.[3]

H. Poincaré developed a theorem with reference to Descartes' rule which connects with Laguerre's theorems.[4]

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[1] *American Journal of Math.*, Vol. 2, 1879, p. 97.

[2] See the *Oeuvres de Laguerre*, T. I., 1898, "Algebre."

[3] *Nouvelles Annales* (2) T. XIX., 1880.

[4] *Comptes Rendus*, XCVII., 1880, p. 1418.

Laguerre suggested methods of approximation which, like Cauchy's, are related to the Newton-Raphson procedure.

In 1884 Laguerre published the following: If $f(x)=0$ is an algebraic equation[1] with real coefficients, λ an arbitrary real number, and $f(x)=(x-\lambda)\,F(x)+f(\lambda)$, then $x=\lambda-\frac{f(\lambda)}{F(x)}$ when x is a root of $f(x)=0$. Taking now

$$\varphi_{k+1}=\lambda-\frac{f(\lambda)}{F(\varphi_k)}$$

as a recurring formula and, starting with a positive value φ_0, form a series of values, $\varphi_0, \varphi_1, \varphi_2, \ldots$ Then $lim\ \varphi_n$ is the root of the given equation next above φ_0, provided $f(\varphi_0)<0$; if $f(\varphi_0)>0$, then $lim\ \varphi_n$ is the root next below φ_0. If such a root does not exist, this fact is revealed by the appearance of negative values in the series of φ's.

Laguerre's researches ought to find their way into textbooks on the theory of equations. Among the texts which do refer to his researches are the higher algebra (part I) published in 1882 in St. Petersburg by the Russian Sohotzky, and the book issued by J. Sochocki in 1884 in Warschau.[2]

Investigations connecting with those of the French writers of the first part of the century were carried on about this time in Russia by A. N. Miassojedoff.[3] He multiplies the members of $f(x)$, one after the other, by $m-k, m-k-1, \ldots, -(k-1), -k$ and from this new polygon leads up to theorems analagous to the theorems of Budan, Fourier and Sturm, which may be applied to the solution of numerical equations as are the latter.

This is a convenient place to mention a paper by Jos. Kolbe[4] who proved that, if in $(fx)=0$ an even number n of consecutive terms is missing, then there exist at least n complex roots, that if an odd number n of consecutive terms is

[1] *Nouvelles Annales*, (3) T. 3, 1884, p. 113.

[2] *Jahrbuch ueber die Fortschr. der Math.*, Vol. XV., p. 55; Vol. 16, p. 68.

[3] *Mosk. Math. Samml.* Vol. 12, pp. 757-797; *Jahrbuch u. d. Fortschr. der Math.*, Vol. 18, 1886, p. 71.

[4] *Wiener Berichte*, Vol. 67, 1873, pp. 188-190.

missing between two terms of like or unlike signs, then the number of complex roots is $n \pm 1$ according as the signs are like or unlike. The article contains no historical references to De Gua or any other author.

We proceed to mention the numerous commentaries that have been made during the past half century upon the Newton-Raphson and allied processes. Lack of space prevents us from preparing an adequate account of each paper. As a rule the papers are of theoretical, rather than practical interest, or else they represent individual preferences in computation which have failed to attain popularity. It is not improbable that some of these papers contain ideas which future elaborators of methods may develop with success.

One of the points which has vexed computers since the time of Newton is that the Newton-Raphson process does not reveal, without the application of special tests, how many digits in the approximation are correct. Special tests have been suggested at various times, but none has met with general favor. Such a test was advanced in 1831 by Fourier. A modification of it was proposed in 1860 by W. Wagner.[1] The same subject has been considered by E. Schroeder,[2] C. Isenkrahe,[3] E. Netto,[4] F. Franklin.[5]

Ch. Michel[6] points out that a certain expression sometimes used in the Newton-Raphson process to indicate the approximation reached is incorrect. His article incited J. Richard[7] to point out how the error after n successive applications of the formula may be calculated. Another formula was suggested by E. Cahen.[8] The practical computer does not take kindly to learning new formulas of this type and to

[1] *Bestimmung der Genauigkeit, welche die Newton'sche Methode zur Berechnung der Wurzeln darbietet*, Leipzig, 1860.
[2] *Math. Annalen*, Vol. 2, 1870, p. 317.
[3] *Math. Annalen*, Vol. 31, 1888, p. 309.
[4] *Math. Annalen*, Vol. 29, 1887, p. 141.
[5] *Am. Jour. of Math.*, Vol. 4, 1881, p. 275.
[6] *Revue de Math. spéciales*, T. 8, pp. 89-90, 113-115.
[7] *Revue de Math. spéciales*, T. 8, pp. 137-138.
[8] Ibidem, T. 8, pp. 152, 339.

submitting himself to extra computation, simply to ascertain the degree of approximation already reached. Hence, none of these tests has met with wide acceptance.

A somewhat different plan was suggested in 1826 by Dandelin, which was then new, but has been repeatedly made later by others, namely the combination of the Newton-Raphson process, with that of double position, so as to have both an upper and a lower limit for the root, at every stage of the process. Dandelin gives a very pretty geometric exposition of this combination process.

Developing a principle set forth by E. Jablonski,[1] Ch. Michel[2] likewise suggests this union of the Newton-Raphson process and the *regula falsi*. Each method separately does not, he says, give a clue as to the degree of approximation reached, but the two together supply both an upper and a lower limit of a root, and, therefore, yield the desired information. This union of methods is meeting with some favor, it being adopted also by H. Weber.[3]

A different alliance of the Newton-Raphson method is suggested by Vincent[4] who develops properties of continued fractions and then deduces a mixed method of computing the real roots in which he combines the rapidity of the Newton-Raphson method with the surety of that of Lagrange. This same union was advocated in 1848 by O. Berger[5] in Lembo.

An interesting paper dealing with some points of the Newton-Raphson method, not often discussed, and at the same time offering a mechanical process of approximation worthy of attention, was published by Joseph Horner[6] in 1860. He speaks of W. G. Horner as "my late relative." On Fourier's statement that if there is one root between a and b, and the curve is convex toward the axis of x in the

[1] *Bull. d. Mathématiques spéciales*, juin, 1895.
[2] *Revue de Math. spéciales*, T. 8, pp. 89-90, 113-115.
[3] *Lehrb. d. Algebra*, 2 *Aufl. Bd.*, I., p. 379.
[4] *Journal d. math. pures et appliq.* (Liouville), T. 3, 1836, pp. 341-372.
[5] *Programm des Gymnasiums zu Lembo*, 1848-49.
[6] *Quarterly Journal of Pure and Applied Math.*, Vol. III., 1860, pp. 251-262.

interval between a and the root-value, the approximation may be continued from a with certainty, Joseph Horner remarks: "In reality, however, it is often found to be far shorter and more convenient to commence from b, and it is therefore essential to the completeness of his theory to determine when this may be safely done." Then Horner proceeds to elaborate analytically what was done geometrically a hundred years earlier by Mourraille. Joseph Horner develops the root of an equation in a series of aliquot parts, $a+\frac{1}{q}+\frac{1}{qq_1}+\frac{1}{qq_1q_2}+\ldots$ The form of expression in "aliquot parts" had been used by Lambert as early as 1758, then by Lagrange,[1] and by Fourier in his great work of 1831, p. 38. It is referred to again soon after J. Horner by Bellavitis[2] in his memoir of 1860.

With the aim of facilitating safety of procedure, by fixing two limits for each approximation, the Newton-Raphson method was studied by A. Genocchi,[3] and later by G. Janni.[4] Both connect with the work of Cauchy on this subject. A modification involving the use of two limits at each step was given also by J. Dienger.[5]

An extension of the Newton-Raphson method is given by A. Miller,[6] who solves $\varphi_x=0$ by writing $\varphi_x=f_x+ax+b$, then finding the intersection ω of the curves $y=f_x$ and $y=-(ax+b)$ whereupon $\mu=(\omega f^1{}_\omega-f_\omega-b)\div(f^1{}_\omega+a)$ is the second approximation. The formula reduces to the one of Newton-Raphson when $a=b=0$.

An algorithm aiming to secure rapid convergence in the case of multiple roots when the Newton-Raphson method yields an acceleration towards the roots of linear order only,

[1] *Journal Ecole Polyt.*, Vol. 2, p. 93.

[2] *Memorie dell'I. R. Istituto Veneto di scienze*, 1860, p. 200.

[3] *Giornale di Matematiche*, Vol. 2, 1864, p. 27.

[4] Same journal, Vol. 8, 1870, pp. 157-160.

[5] *Differential und Integral Rechnung 2. Aufl.*, §63; *Theorie u. Aufl. d. hoh. Gleichungen*, Stuttgart, 1866, p. V.

[6] *Blätter f. d. bayrische Gymnasial & Realschulwesen* (München) Vol. XI, 1875, pp. 350-361.

was worked out in 1876 by H. Eggers[1] of Milwaukee. If x_0 is an approximate value, then a corrected value, x_1, by a convergence of the quadratic order, is obtained by the formula $x_1 = x_0 - f(x_0) \cdot f'(x_0) \div \{[f'(x_0)]^2 - f(x_0) f''(x_0)\}$. Eggers remarks that an infinite number of formulae of every possible rate of convergence are possible, but in case of a high order of convergence the amount of work demanded by the formulae offsets the advantage due to rapid convergence. Eggers was educated in Germany, and E. Schröder expresses his indebtedness to him on the subject of numerical equations.[2]

L. Maleyx who in 1860 had published in Paris a method of separating the roots, in 1879 institutes a comparison between the Newton-Raphson method and the one by proportional parts, and concludes that the latter is preferable when an upper and a lower root limit are initially given.[3]

K. V. Zenger[4] gives a method of solving numerical equations by logarithms which E. Malo[5] has shown to be related to the Newton-Raphson formula from which it differs by a term of the second order. Malo elaborates in his own way an old idea that if $f(x)$ be transformed into $F(x)$ by increasing the roots of $f(x)$ by a constant, then the approximate root-values of $F(x)$ may be used advantageously in the solution of $f(x)$.

In an article, *Sur la résolution numérique des équations*,[6] H. Amstein, professor at the Académie de Lausanne, declares that there are three methods of approximation in practical use: the regula falsi, "Newton's method," and Horners'. The first does not reveal the degree of approximation reached; the second does reveal this, if one computes the neglected term $f''(a)\frac{h^2}{2}$; the third applies, he says, only to algebraic

[1] *The Analyst*, (J. E. Hendricks), Vol. III., 1876, pp. 149-150.

[2] *Math. Annalen*, Vol. II, 1870, p. 317.

[3] *Nouvelles Annales de Math.*, 2. S., Vol. 18, 1879, pp. 218-232.

[4] *Casopis; Zeitsch. sur Pflege d. Math. u. Physik*, Prag, Vol. XI., 1882, pp. 288-291.

[5] *Nouvelles Annales* 3ieme S., T. 11, 1892, pp. 169-178.

[6] *Bull. de la Société Vaudoise d. sciences nat.*, 2e S., Vol. XX., Lausanne, 1885, pp. 201-212.

equations. The first replaces the given curve by a chord; the second by a tangent. Amstein himself suggests a new method, "la méthode des trois points," which replaces the curve by a conic (say a hyperbola) having three points in common with it. Two points are chosen on the given curve near a root and a third is obtained by the regula falsi. Then a further approximation is reached by an expression in the form of an algebraic fraction.

Another modification of the Newton-Raphson formula was given by E. Kobald[1] who secures more rapid convergence by writing

$$x=a-\left[\frac{f'(a)}{f(a)}-\frac{\frac{1}{2}f''(a)}{f'(a)}\right]^{-1}$$

Again another modification of the Newton-Raphson method is given by Th. Lohnstein.[2]

J. W. Nicholson[3] proposed a general formula which includes the Newton-Raphson one as a special case.

G. Fouret[4] in 1891 made a study of the conditions which are both necessary and sufficient for the safe application of the Newton-Raphson process.

F. J. Van den Berg[5] points out that, just as the Newton-Raphson formula represents the value of the subtangent to the curve $y=f(x)$, so $x=[bf(a)-af(b)]\div[f(a)-f(b)]$ represents the intercept of the secant passing through the points on the curve corresponding to $x=a$ and $x=b$, and this formula can be used in approximations.

The Newton-Raphson process has been discussed also by F. Giudice, who in 1886[6] and 1903[7] made a new study of the separation of the roots, and offered methods of approximation

[1] *Monatshefte f. Mathematik u. Physik*, Vol. II., 1891, pp. 331-332.

[2] *Zeitschr. f. Math. u. Phys.*, Vol. 36, 1891, pp. 383-4.

[3] *Direct and General Method of Finding the Approximate Values of the Real Roots of Numerical Equations*, New Orleans, La., 1891.

[4] *Sur la méthode d'approximation de Newton*, Paris, 1891.

[5] *Amst. Versl. en Meded* (3) IX., 53-67. See also *Jahrbuch ueber d. Fortschr. der Math.*, Vol. 24, 1892, p. 103.

[6] *Rendiconti del Circolo matematico*, T. I., 1884-1887, pp. 69-72.

[7] *Giornale di matematiche* (Battaglini) Vol. 41, pp. 190-191.

to the roots.[1] In France, recent studies along this line have been made by A. Pellet,[2] and by R. Perrin.[3] Both Pellet and Perrin employ the device which we have seen followed also by Mehmke in Germany, of separating the terms of an equation into two polygons each of which contains only terms of like sign.

2. THE RUFFINI-HORNER METHOD.

One desideratum which eighteenth century mathematicians failed to supply was a short practical method of transforming one equation into another whose roots are all diminished by a certain constant. At the beginning of the nineteenth century several inventions were made in the effort to meet this want. Perhaps the first to suggest an algorithm was Paolo Ruffini (1765-1822), professor of mathematics in Modena and well-known for his work on the impossibility of solving algebraically the quintic equation. The Italian scientific society had in 1802 offered a gold medal for improvements in the solution of numerical equations, and it was awarded in 1804 to Ruffini for his *Memoria* on this subject.[4]

Most interesting is Ruffini's mode of effecting the transformation referred to above. The theory of this transformation is worked out with the aid of the calculus somewhat as was done by several eighteenth century mathematicians. Then follows the mechanism for the practical computer, and here Ruffini has a device which is simpler than Horner's scheme of 1819 and practically identical with what is now known as Horner's procedure. The actual computations are absolutely identical. The only difference is that in Ruffini's arrangement the coefficients of the transformed equation

[1] *Rendiconti del circolo matematico*, T. XVI., 1902, pp. 180-184; *Giornale di matematiche* (Battaglini), Vol. 41, 1903, pp. 14-20.

[2] *Comptes Rendus*, T. 133, 1901, pp. 917, 1136; *Société math. de France*, T. 29, 1901, pp. 139-142; *Assoc. Franç.*, 31, (Montauban), pp. 166-171.

[3] *Comptes Rendus*, T. 133, p. 1189; *Assoc. Franç.*, 31, (Montauban) pp. 178-185.

[4] P. Ruffini, *Sopra la determinazione delle radici nelle equazioni numeriche, di qualunque grado*, Modena, 1804.

appear at the end of the operation grouped in a column, while in Horner's process these coefficients are arranged along a diagonal. One arrangement is about as good as the other. The conclusion forces itself upon us that Horner, in what is known as "Horner's method" was anticipated fifteen years by our gifted Italian.

As is now frequently done in Horner's method, Ruffini avoids decimal fractions by multiplying the roots of every transformed equation by 10. In the case of negative roots he writes $-x$ for x. Ruffini explains his procedure by solving Newton's cubic, but part of the computation is suppressed. He devotes much space to the limits between which all the real roots of an equation lie, and to the limits of each separate root.

Ruffini published a second article nine years later[1] in which he remarks that he explained his method of solving numerical equations in the appendix to his *Algebra Elementare*, which appeared in two volumes in 1807 and 1808. In this second paper Ruffini applies his method to the extraction of roots of numbers and gives in full several illustrations of the process. He explains also how the process may be contracted. Thereupon he proceeds to a derivation of his method of solution by elementary processes, without the use of the differential calculus.

When we compare Ruffini's and Horner's labors on numerical equations, we notice an interesting parallelism; (1) Independently the two hit upon almost identically the same method, (2) both used in their first expositions the higher analysis, (3) both explained the method later by the process of elementary algebra, (4) both offered the method as a substitute for the old process of root-extraction of numbers.

A mechanism for effecting the transformation named above was invented also by Budan and explained in his pub-

[1] "Di un nuovo metodo generale di estrarre le radici numeriche" in *Memorie di matematica e di fisica della società italianna delle scienze*, Verona, 1813, T. XVI., parte I, pp. 373-436; T. XVII., Parte I, pp. 1-15.

lications of 1807 and 1822.[1] He claimed for it the advantage of involving only additions and subtractions. His process of transformation by which the roots are diminished by 1 is practically the same as the process given previously by Ruffini and identically the same with the well-known process named after Horner. But here the resemblance ends. A diminution of the roots by 2 or 3 is brought about by 2 or 3 repetitions of the process for diminishing by 1. The operation becomes unnecessarily tedious when the roots are diminished by 7, 8, or 9.

Passing to England, we enter now upon the closer study of the researches of Horner. William George Horner (1786-1837), of Bath, was the son of a Wesleyan minister. He was educated at Kingswood school, near Bristol, and at the age of sixteen began his career as a teacher in the capacity of an assistant master. His method of solving equations was read before the Royal Society, July 1, 1819, and published in the *Philosophical Transactions* for the same year[2] under the title, "A new method of solving numerical equations of all orders, by continuous approximation." The paper was reprinted in the *Ladies' Diary* of 1838. A full account of Horner's discovery is given in the first volume (1845) of the *Mathematician* and in De Morgan's article in the *Companion to the British Almanac* for 1839. We shall make extensive use of the latter article. Horner uses Arbogast's derivatives. In fact, the modern reader who is familiar with the very simple and elementary explanation of Horner's method found in texts of the present day is surprised to find Horner's own exposition involved in reasonings very intricate and making a large demand upon the more recondite branches of analysis. In principle his method had been known for more than two hundred years, ever since the issue of Vieta's epoch-making research: in careful adaptability of the process

[1] *Nouvelle méthode pour la résolution des équations numériques*, Paris, 1807. Chap. II.

[2] *Dictionary of National Biography*, (Leslie Stephen).

to the practical needs of the computer, Horner and Ruffini have no predecessor. Horner never knew of Ruffini's researches on this subject. The theory of the method was stated distinctly in Horner's own time in ordinary text-books, such as Garnier's *Elemens d'Algèbre*, 1811, p. 399 and still more so in Francoeur's *Mathématiques*, 1819, T. II., p. 37.[1] Yet the practical possibilities of it in the solution of equations was not observed in England till the publication of Horner's researches. Horner mentions in his article many mathematicians, but does not refer to Vieta's, Harriot's, Oughtred's, Wallis's, Newton's and Ruffini's modes of approximation. Having failed to familiarize himself with the history of his subject, Horner no doubt thought that he was the inventor of the principle of his method, as well as of the practical arrangement of the computation.[2] This arrangement, it should be noted, is not quite the same as the one now explained in text-books as Horner's process, but the difference is slight.

Horner offers his method as a substitute for the old processes of extracting pure roots, as has since been done by De Morgan and others.

Horner makes in his paper the extraordinary claim that his method of approximation applies also to irrational and transcendental equations. He says: "From the unrestricted nature of the notation employed, it is evident that no class of equations, whether finite, irrational or transcendental, is excluded from our design." But he gives no illustrative solutions of such equations. His scheme of solution as shown

[1]See J. R. Young, *Algebraical Equations*, 2nd Ed., London, 1843, p. 47. The first edition of this book, which treats more fully of the solution of numerical equations than any other English work of that time, appeared in 1835.

[2]Having probably the old Newton-Leibnis controversy in mind, Horner writes in a foot-note, p. 308: "The only object proposed by the author in offering this essay to the acceptance of the Royal Society, for admission into the Philosophical Transactions, is to secure beyond the hazard of controversy an Englishman's property in a useful discovery. Useful he may certainly be allowed to call it, though the product of a purely mathematical speculation; for of all the investigations of pure mathematics, the subject of *approximation* is that which comes most directly and most frequently into contact with the practical wants of the calculator."

in his "tabular form" makes no provision for functions yielding a never ending series of derivatives. The scheme, as it stands, is inapplicable to irrational and transcendental equations.

Horner's original paper did not sufficiently consider the case of nearly equal roots. The difficulty of separating them is great if the trial divisor alone is depended upon for the discovery of the successive figures of the root. Horner removed this imperfection in a second paper, published in *Leybourn's Repository*, Vol. 5, part II., London, 1830, p. 63. Being unaware of the existence of this second article, J. R. Young, professor of mathematics in Belfast College, elaborated this point independently.[1] Researches along this same line were carried on later by Schulz von Strassnitzki.[2]

Horner's own mechanical arrangement of the computation did not meet the full approval of the great champions of his method—J. R. Young and A. De Morgan. These men slightly modified Horner's original scheme, so as to provide against the entrance of unnecessary decimals into the several columns of the work. Young, in particular, criticized Horner's scheme of contraction as retaining useless figures in some parts and dismissing effective ones in other parts. Young presented modified schemes in his *Algebraical Equations*, chapter XII.

The great practicability of Horner's modified method is pointed out by De Morgan[3] by applying it to an example taken from Wallis, in which De Morgan "omits no process except such as are usually omitted in common multiplication and division, and the number of figures is under 730. The process in Wallis has more than 1100 figures *written down*; and, if all those additions were made which would render it as complete as the preceding, we imagine that the 1100 figures would be at least trebled in number."

[1] *Algebraical Equations*, 1843, pp. 260-263.

[2] See S. Spitzer, *Allgem. Aufl. d. Zahlengleichungen*, Wien, 1851, p. 8.

[3] *Comp. to the British Almanac*, 1839, pp. 51, 52.

Looking back over 200 years we see that to Vieta belongs the extension of the process of evolution so as to apply to affected equations; to Newton, the addition of a more convenient divisor, and to Ruffini and Horner, the simplification of the process of finding the Newtonian divisors.[1]

As regards the priority of invention, Horner did not escape rival claimants, even among his own countrymen. Their claims are fully discussed by De Morgan,[2] and, as the original publications are not accessible to us, our remarks are based entirely upon his article.

In June, 1820, a tract was published by Theophilus Holdred, entitled, "A new method of solving equations," with a supplement. The tract itself was, according to De Morgan, "the old method in a modern form, and with no more difference than the application of the usual modern forms and the use of Newton's divisor instead of Vieta's," the supplement was "neither more nor less than the method which Mr. Horner had put in print more than six months before." Holdred claims to have been in possession of the method described in his tract for forty years and that the process described in the supplement occurred to him while the tract was going through the press (after the publication of Horner's paper).

The second claimant is Peter Nicholson, who had seen Holdred's first method before it was published and suggested some improvements which Holdred declined to publish. Thereupon Nicholson published his essay, on "Involution and Evolution," in 1820. In the preface he says of Horner's paper: "I perceived, however, that the paper contained the substance of what I had previously written and published." The earlier publications of Nicholson, here referred to, were examined by De Morgan and found inadequate as a basis for a claim of priority.

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[1] *Op. cit.*, p. 48.

[2] *Companion to the British Almanac*, 1839, pp. 40-52.

The third and last claim is contained in a posthumous tract of Henry Atkinson of Newcastle, entitled, "A new method of extracting the roots of equations; read at the Literary and Philosophical Society of Newcastle-upon-Tyne, August 1, 1809," Newcastle, 1831. His method was that of Vieta somewhat like the form in which Wallis left it, but with the use of the Newtonian divisor, and the use of Newton's approximation at the conclusion. Or, as De Morgan finally puts it, "Mr. Atkinson's method is Newton's approximation, rather than Vieta's, digested so as to furnish figure by figure . . . He consequently made a real step on the road, which had not time to become known before it was rendered useless by the 'capital improvement' of Mr. Horner."

A method much resembling that of Atkinson was made public some time between 1690 and 1694 by Richard Sault in a work called "A new treatise of algebra, with a converging series for all manner of adfected equations." It is Raphson's method, made to proceed by single figures of the root.

The nearest approach to a successful rival of Horner on British soil was named by Horner himself in his second paper,[1] namely Alexander Ingram, who applied the method in extracting cube roots and published an account of it in his edition of Hutton's Arithmetic (Edinburgh, 1807), and in his edition of Melrose's Arithmetic, 1816.

As has been already pointed out, Horner was fortunate in finding in England two influential champions of his method —J. R. Young and A. De Morgan. Encumbered by an abstruse mode of exposition, Horner's paper was in danger of falling into unmerited neglect. The simple and elementary form which the method now has was given to it principally by Young and De Morgan. Young explained it in his *Algebra*, London, 1826, and in his *Algebraical Equations*, London, 1835, 2nd ed., 1843. De Morgan described it in the *Penny Cyclopedia*, article "Involution and Evolution," and

[1] *Leybourn's Repository*, Vol. 5, part II., p. 52; See also *The Mathematician*, Vol. III., p. 289.

in the *Companion to the British Almanac* for 1844. De Morgan advocated the use of this method for ordinary root-extraction. He complained that in the universities there existed no disposition to encourage computation among mathematicians. He taught Horner's method to his classes, and derided the examiners at Cambridge who ignored the method.[1] He encouraged students to carry out long arithmetical computations for the sake of acquiring skill and rapidity. Thus, one of his pupils solved $x^3-2x=5$ to 103 decimal places, "another tried 150 places, but broke down at the 76th, which was wrong."[2] Following the suggestion of De Morgan, Horner's method has been recommended for square and cube root in elementary instruction by E. M. Langley and R. B. Hayward,[3] but with all its simplicity it is not likely to carry the day in competition with the older methods which require only a grasp of the expansions of $(a+b)^2$ and $(a+b)^3$.

The synthetic division, by detached coefficients, used in Horner's process, was proved to be true by a writer signing himself D. V. S. in the *Mathematician.*[4] This matter is taken up in detail in the third and last important paper written by W. G. Horner himself. The first paper, it will be remembered, appeared in 1819, the second in 1830, the third, "On Algebraic Transformations" was published in 1845 as a posthumous article.[5] It had been read before the Royal Society, June 19, 1823, but as T. S. Davies explains, in an introductory note to the article, was refused publication in the Philosophical Transactions, even after it had been considerably curtailed. Horner often stated to Davies that much demur was made to the insertion of his first paper in the Philosophical Transactions. "The *elementary character* of the subject,"

[1] See De Morgan, *Budget of Paradoxes*, 1872, pp. 292, 373-5.

[2] Graves, *Life of Sir Wm. Rowan Hamilton*, III., p. 275.

[3] See *Report of the Ass'n for the Impr. of Geom. Teaching* for 1889, pp. 59-68; and for 1892, p. 40.

[4] *The Mathematician*, edited by T. S. Davies, W. Rutherford and S. Fenwick, London, Vol. I., 1845, pp. 74-76.

[5] *The Mathematician*, Vol. I., 1845, pp. 108-112, 136-142, 311-316; Vol. II., pp. 32-37, 129-132.

says Davies, "was the professed objection; his recondite mode of treating it was the professed passport for its admission." Horner's third article was a simplification of the principles of his process. He still shows a very limited knowledge of the literature of the subject. Interesting is his reference to Budan, of whom he says: "I am satisfied with finding that he had not anticipated my discovery." Of his real anticipator, Ruffini, he makes no mention.

The method of approximation published by Horner in 1819 received little attention in England for fifteen years. R. Stevenson's *Algebraic Equations*, 2nd Ed., Cambridge, 1835, and R. Murphy's *Algebraical Equations*, London, 1839, do not mention him, but J. R. Young's *Algebraical Equations*, London, 1835 and 1843 lays great stress upon his method. We pointed out earlier that Fourier's great work of 1831 was known and admired in England at a time when Horner's research of 1819 was still unknown to his countrymen. Nearly a quarter of a century elapsed before any attention to Horner was paid on the Continent. Fourier and Sturm do not mention him; in fact, Horner's method has to this day failed to acquire a foothold in France.[1] There the Newton-Raphson process has maintained its ascendancy. It was in 1842 that Horner's method was first made accessible to German readers by Leopold Carl Schulz v. Strassnitzki of the Polytechnic Institute in Vienna, in a publication, *Neue Methode zur Auflösung höherer numerischer Gleichungen*, Wien, 1842. Then followed expositions by Simon Spitzer,[2] in 1849 and 1851, C. H. Schnuse[3] in 1850, H. Scheffler[4] in 1859, Joseph J.

[1]For instance, no explanation of Horner is given in the following textbooks: J. Vieille, *Théorie générale des approximations numériques*, Paris, 1854; L. Saint-Loup, *Traitdé e la résolution des équations numériques*, Paris, 1861; J. A. Serret, *Cours d'algèbre supérieure*, Paris; A. Xavier, *Approximations numériques*, Paris, 1909.

[2]Simon Spitzer in *Naturwissenschaftliche Abhandlungen*, Vol. III., 2 Abth., Wien, 1849, pp. 109-170; *Allgemeine Auflosung der Zahlengleichungen*, Wien, 1851.

[3]C. H. Schnuse, *Theorie u. Auflocs. d. hoeher. algebr. u. d. transc. Gleichungen*, Braunschweig, 1850.

[4]H. Scheffler *Auflocs. d. algebr. u. transc. Gleichungen*, Braunschweig, 1859.

Nejedli[1] in 1858 and 1865, Josef Dvorak[2] in 1865, P. C. Jelinek[3] in 1865, J. Dienger[4] in 1866, Exner[5] in 1859 and 1866.

Notwithstanding all these publications the Ruffini-Horner process never wholly took possession of the German and Austrian territory. As late as 1872 W. Matzka thought it necessary to publish a full account, with detailed explanations, of Horner's method in the transactions of a learned society.[6] The well-known *Lehrbuch der Algebra* of H. Weber, in the edition of 1898, explains the antiquated method of two false positions, but gives no exposition of the Ruffini-Horner process.

In the United States of North America, Horner's method and Sturm's theorem were first introduced into a school book in 1842, when the *Treatise on Algebra* by George R. Perkins was published in New York.

We have called attention to several suggestions of combinations of the Newton-Raphson process with certain other processes. One such suggestion now comes to our notice in connection with the Ruffini-Horner method. C. Runge refers to the ease with which it can be combined with Lagrange's method of continued fractions.[7] After determining the integer a just below a root, put $x=a+\frac{1}{y}$ and consider the equation in y. In applying Horner's mechanical arrangement, the coefficients must be written in reverse order.

A writer who is the author of several memoirs on numerical equations, and has also paid particular attention to the study of researches of earlier investigators, is Giusto Bellavitis[8]

[1]Josef Nejedli in the *Programm d. Kath. Gymnasiums zu Leutschau*, 1858; J. J. Nejedli in *Jahresb. d. k.k. Obergymnasiums zu Laibach*, 1865.

[2]J. Dvorak, in the *Programm d. k. k. Staats-Gymnasium zu Innsbruck*, 1865.

[3]P. C. Jelinek, S. J., *Aufloes. d. hoeher. num. Gleichungen*, Leipzig, 1865.

[4]J. Dienger, *Theorie u. Aufloes. d. hoeher. Gleichungen*, Stuttgart, 1866.

[5]Exner, *Programm, Gymnasium zu Hirschberg*, 1859, 1866.

[6]*Abhandl. d. K. Boemischen Gesellschaft d. Wissensch.*, Prag, (6) Vol. V.

[7]*Encyclopaedie d. Math. Wissenschaften*, Vol. I., Leipzig, 1898-1904, p. 438.

[8]See *Memorie dell'I. R. Istituto Veneto*, (T. III., 1847, pp. 109-219; IV., 1852, pp. 243-344; VI., 1856, pp. 357-413.

(1803-1880) of the University of Padua. No writer on numerical equations, excepting only Lagrange, has shown such intimate familiarity with the publications of predecessors as has Bellavitis. In an appendix to his previous papers, published by the Venetian Institute,[1] he gives a very full bibliography of the subject and adds interesting remarks on the various methods. In 1847 he speaks in high appreciation of Ruffini's method. He himself lays stress upon the determination of the imaginary roots by processes resembling the Ruffini-Horner method for real roots. He breaks $f(x)=0$ up into two equations, one containing the odd powers with every other sign changed, the other containing the even powers with every other sign changed. In these two auxiliary equations he writes $x^2=y$. By playing backward and forward, between the auxiliary equations and the given one, Bellavitis determines the values a and b of a root $a+ib$, one digit at a time, by the Ruffini-Horner process. To make certain that no imaginary roots are overlooked, he suggests a rule which he deduced from the theory of "indices" of Cauchy. In the memoir of 1852 Bellavitis succeeded in simplifying this rule somewhat. In 1856 he returned to the subject again.

The papers of Bellavitis made no impression outside of Italy. In fact we have not been able to satisfy ourselves that they received much attention even at home. It was to be expected that other attempts would be made to extend the Ruffini-Horner method to the determination of imaginary roots. Especially should we look for such researches in localities where the superiority of this method in its adaptability to elementary instruction was recognized. And so we find that such investigations were undertaken in England and in Austria. William Rutherford (1789-1871) of the Military Academy at Woolwich in England, published a paper in 1849 entitled *Complete Solution of Numerical Equations*, which was

[1] *Appendice alle memorie sulla risoluzione numerica delle equazioni, I. R. Istituto Veneto*, 1860, pp. 177-236.

translated into German the same year by August Wiegand and in 1850 explained by C. H. Schnuse in his text on *Algebraische und Transcendente Gleichungen.* Rutherford finds the complex roots of equations of the third, fourth, fifth and sixth degrees by the aid of the real roots and the relations existing between the coefficients of the given equation and the one obtained by diminishing the roots by the real part of two conjugate complex roots.

In the same year, 1849, and again in 1851, Simon Spitzer, in the publications named above, determined the complex roots by applying to them the Ruffini-Horner process for real roots; the equation was transformed by diminishing the roots by $a+ib$. This process demanded that the complex roots be located before the approximation begins. How this location may be accomplished was shown by Schultz v. Strassnitzki, by whose lectures Spitzer was first introduced to the subject of numerical equations. Spitzer's mode of procedure is explained by H. Scheffler in his text of 1859.

An ingenious modification of Horner's method along the lines followed previously by Bellavitis (except that no use is made now of Cauchy's "indices"), was given by P. C. Jelinek,[1] S. J., in 1865. Jelinek was apparently unaware of the researches of Bellavitis. He aimed to develop a process which would reduce the great labor involved in Spitzer's process of computing imaginary roots. The method of Jelinek yields the real and imaginary roots by the aid of auxiliary equations, whose degrees are half that of the given equation or even less. Thus, the solution of an equation of the fourth or fifth degree is carried on with the aid of equations of the first and second degrees, respectively. The process itself reveals the existence of imaginary roots, so that the application of theorems like Sturm's is not needed. Illustrative examples show that this method, though more complicated in theory, is less laborious than that of Spitzer.

[1]P. C. Jelinek, *Aufloes. der hoeh. num. Gleichungen, etc.*, Leipzig, 1865.

Apparently unaware of previous applications of the Ruffini-Horner process to complex roots, Karl v. Mor[1] in 1884 suggests the same method as that of Spitzer, except that he finds, by the intersections of curves, the initial values of a and b, in the quantity $a+ib$ by which the roots are diminished.

About the middle of the century three theses were issued in Germany on the *history* of the theory of equations, the last two of which include accounts of the Ruffini-Horner process, without reference, however, to the part taken by Ruffini. These authors are O. Berger,[2] M. F. Focke,[3] and Theodor Hoh.[4]

3. WEDDLE'S METHOD.

Thomas Weddle (1817-1853) of Newcastle in England, published *A new . . . method of solving numerical equations of all orders*, London, 1842, which is a method kindred to that of Horner. After finding the first digit of the root he corrects this value by successive multiplications, instead of additions. If R is the first significant digit in a root x of $f(x)=0$, divide the roots by R, then $x=Rx_1$. The transformed equation $f(x_1)=0$ has a root x_1 that lies between 1 and 2. Let r_1 be the value of the first significant digit of the decimal part of x_1, and put $x_1=(1+r_1)x_2$. Form the equation $f(x_2)=0$ and assume $x_2=(1+r_2)x_3$, where r_2 is the value of the first significant digit in the decimal part of x_2, and so on. The root x is given by the equation $x=R(1+r_1)(1+r_2)$ . . .

Weddle devised a mechanical process of carrying out the transformations which is analogous to that of the Ruffini-Horner process. Weddle's method has considerable advantage when the degree of the equation is high and some of

[1] *Programm d. k. k. Ober-Reaschule zu Innsbruck fuer d. Studienjahr* 1883-4, Innsbruck, 1884.

[2] *Programm des Gymnasiums zu Lembo fuer d. Schuljahr* 1848-49.

[3] *De aequationibus numericis superioris ordinis*, Monasterii, Typis Theissingianis.

[4] *Programm zur Schlussfeier d. Studienjahres* 1858-59, K. Bayer, *Lyceum, Gymnasium zu Bamberg.*

the terms are missing. While in Horner's method missing terms require as much attention in the process of approximation as any others, in Weddle's process they are ignored, as coefficients corresponding to them do not appear during computation.

Weddle's paper was read before the Royal Society of London, but the Society declined to print it in its Transactions. A. De Morgan, who admired Weddle's new method, criticized the Royal Society for its lack of appreciation.

References to Weddle's method are found in a few Italian and German publications, but we have seen no references to it in French books. A full exposition was given in 1850 by C. H. Schnuse of Heidelberg in his book *Die Theorie und Auflösung der . . . Gleichungen*, II. Kapitel. That Schnuse's excellent account of Weddle's method failed to make it generally known in Germany, is evident from a paper published in 1878 by A. Giesen.[1] Giesen expresses a root known at the start to be near φ, by the formula

$$\varphi\left(1+\frac{\beta}{10}\right)\left(1+\frac{\gamma}{100}\right)\cdots$$

where β, γ, may be single digits, and also by the formula

$$\varphi+\frac{b}{B}+\frac{c}{B^2}+\frac{d}{B^3}+\cdots$$

where the numerators are integers. The first of the two formulæ is a re-establishment of the process of Weddle, only Giesen missed Weddle's pretty mechanism in conducting the computation. Giesen was unaware that his method of factors had been given before.

And yet it was in Germany and Austria that Weddle's method received important extensions. When Simon Spitzer saw Schnuse's account of the method, he extended it to the computation of complex roots and published his invention in an appendix to his paper entitled, *Allgemeine Auflösung*

[1] *Zeitschr. f. Math. u. Physik* (Schlömilch), Vol. 23, 1878, pp. 35-46.

der Zahlengleichungen, Wien, 1851. In 1862 an extension to complex roots was described by Josef Popper,[1] but Spitzer complains[2] that Popper reproduced, without acknowledgment of indebtedness, his own solution of 1851, concerning which he had spoken to Popper about four years previous to the time of Popper's publication.

Weddle's method was recommended to the attention of mathematicians by Bellavitis[3] who published an account of it drawn from Schnuse's book.

4. THE DANDELIN-GRÄFFE METHOD.

Dandelin's article of 1826,[4] which we found to contain interesting researches on the Newton-Raphson process, contains in its second supplement a new and masterly device for approximating to the roots of an equation, which constitutes an anticipation of the famous method of Gräffe. If the root-limits are a and b, $a-b<1$, and a on the convex side of the curve, he puts $x=a+y$ and transforms the equation into one whose root y is small. He then multiplies $f(y)$ by $f(-y)$ and obtains, upon writing $y^2=z$, an equation of the same degree as the original one, but whose roots are the squares of the roots of the equation $f(y)=0$. He remarks that this transformation may be repeated, so as to get the fourth, eighth, or still higher powers.

In the development of this last method, Dandelin represents all roots, whether real or imaginary, by the symbolism $\rho\ (\cos\theta+i\sin\theta)$ and establishes the theorem: If an equation $f(x)=0$ has $m+n$ roots, and the moduli of the first m roots are very great as compared with the moduli of the last n, then the first m are roots of an equation composed of the first $m+1$ terms of $f(x)=0$, while the last n are

[1] *Zeitschr. fuer Math. u. Physik*, Vol. VII, 1862, p. 384.

[2] Ibidem, Vol. VIII, 1863, p. 240.

[3] Appendice alle memorie sulla risoluzione, etc., in *Memorie dell'I. R. Istituto Veneto*, 1860, pp. 178, 192.

[4] *Nouveaux mémoires de l'académie roy. d. scien. et bell. de Bruxelles*, T. 3, 1826, pp. 7-71.

roots of one composed of the last $n+1$ terms. Instead of simply two, one may consider several orders of modular magnitudes. By transforming the given equation a sufficient number of times, the moduli of the powers of the roots diverge sufficiently to make the transformed equation *separable* into as many polygons as there are roots of distinct moduli. He explains how one can tell when an equation is separable, and how the real and imaginary roots can be obtained. Unfortunately there is at this point a lack of detail and of illustrative examples, though he says he has used this method often.[1]

Dandelin's great research had the misfortune of being buried out of sight in the ponderous tomes of a royal academy. Writers on numerical equations do not refer to it. Only Bellavitis was aware of the paper, but his interest was not centered upon the part of it which discusses the topic now under consideration. The evolution of this subject proceeds therefore as if Dandelin's genial contribution had never been made.

The approximation to the real roots of equations had been put upon a fairly satisfactory basis by the researches of Fourier. The Ruffini-Horner process made it still more satisfactory, though at the time now under consideration (1831-1842) it was still unknown on the Continent. The problem naturally arose, to invent, if possible, methods of approximating also to the imaginary roots. The problem was not new. It had been studied in the eighteenth century and received a solution by Waring, Euler and Lagrange. But these solutions were theoretical, rather than practical. The amount of computation involved was so enormous that no one ever thought of actually using the methods on a problem. In the early part of the nineteenth century Legendre, Polctti, Fourier, Stern and Cauchy failed to make substantial headway toward a practical method.

[1]For biographical details about Dandelin, see A. Quetelet *Sciences Math. et Phys. chez les Belges*, 1866, "Index."

Dandelin had a brilliant idea, but did not sufficiently elaborate it, and failed, as we have seen, in securing the ear of the scientific public. Hence no practical method of computing all the imaginary roots of a numerical equation was generally known in 1835. It was therefore natural for the Academy of Sciences of Berlin to offer a prize for the invention of a practical method. The prize was awarded to Carl Heinrich Gräffe (1799-1873), professor of mathematics in Zürich, for his paper, published in 1837 in Zürich, entitled, *Die Auflösung der höheren numerischen Gleichungen.* This publication contains not only the method now generally known as "Gräffe's method," but also the older methods known to him, which he discusses and finally rejects as impractical. His discussion of the method of recurrent series will be referred to in the part of our article which deals with that method.

Gräffe proceeds from the same principle as did Stern in the method of recurrent series. He, too, causes the smaller roots to vanish in comparison with the larger, by the process of involution to higher and higher powers. From the given equation both writers derive new equations, whose roots are high powers of the roots of the given equation. From the coefficients of the latter they obtain the real roots and the moduli of the imaginary roots. But the mode of procedure by which these powers are gotten is different with the two men. Gräffe does not use the symmetric formulae for the sums of powers of the roots; he attains his end by successive steps of involution. He first derives an equation whose roots are the squares of the roots of the equation to be solved. Then he finds the equation whose roots are the squares of the roots of the derived equation, and so on. The roots of the successive equations gotten by this process are, respectively, the 2nd, 4th, 8th, 16th, 32nd, 64th, etc., powers of the roots of the initial equation. The law by which the new equations are constructed is exceedingly simple. Thus, if

the coefficient of the fourth term of the given equation is a_3, then the corresponding coefficient of the first transformed equation is $a_3^2-2a_2a_4+2a_1a_5-2a_6$. In the computation of the new coefficients, Gräffe uses logarithms. Suppose the last transformed equation contains roots that are the rth powers of the roots of the given equation. If then, we find the rth root of each coefficient, and divide each result by the preceding one, we obtain the absolute values of the real roots. Their algebraic signs can be easily determined. In the case of imaginary roots the process yields merely the modulus. Gräffe determines the amplitude by a special method.

The method of Gräffe possesses some very unusual advantages. In the first place all the roots of the equation, both real and imaginary, are found simultaneously. In the second place it dispenses with the necessity of determining beforehand the number of real roots and imaginary roots, and the location of each root. If one recalls the amount of effort put forth during two centuries to devise expeditious and reliable means to do this, one appreciates a mode of approximation which does away with these perplexing and time absorbing preliminaries. The presence of imaginary roots is revealed by the behavior of the coefficients of the successive transformed equations. If the rth coefficient in the successive terms fluctuates, it reveals the presence of imaginary roots in the initial equation. Gräffe gives his attention also to the case of equal real roots.

The astronomer Encke expressed himself on Gräffe's method as follows: "The method commends itself by its generality, rigor and brevity. It is direct, inasmuch as it does not call for trials of any sort. It is applicable to all equations, of any degree; it does not lead to equations of higher degree than that of the first and in its uniform and unvarying mode of procedure never calls for an insuperable amount of computation. The nature of the roots and the number of imaginary ones present no obstacle in its path."

The only objection to Gräffe's method is that the transformations demand considerable time, even when logarithms are used. If all the roots of an equation are sought, then this method possesses very marked advantages; if only some particular root is sought, then other modes of approximation become successful rivals.

The determination of equal roots and imaginary roots requires more time than that of real roots, but not to the extent that the older methods do. Gräffe does not consider the case of equal imaginary roots. This and some other matters are discussed in the very able and elaborate article by the astronomer J. F. Encke (1791-1865), from which the above quotation is taken.[1]

An independent and greatly simplified exposition of the theory of the Dandelin-Gräffe method was given over half a century later by E. Carvallo.[2] Carvallo's exposition resembles in some parts that of Dandelin, although Carvallo had not seen Dandelin's paper. Carvallo extends the method not only to algebraic equations with complex coefficients, but also to transcendental equations. His fundamental theorem relates to the "separation" of two consecutive roots, (the roots being arranged according to the values of their moduli), so that, compared with the first root, the value of the second is negligible. He establishes a necessary and sufficient test for the possibility of separation, whereby the polynomial $f(x)$ divides itself into two parts. The first part by itself gives the larger root and the roots preceding it; the second part gives the smaller of the two roots and all that follow it.

Carvallo criticizes Gräffe and Encke for lack of rigor and for failure to recognize that the entire theory can be founded upon one fundamental principle. In criticism of Carvallo's

[1] J. F. Encke, "Allgemeine Auflösung der numerischen Gleichungen" in *Berliner Astronomisches Jahrbuch fuer* 1841, also in *Crelle's Journal*, Vol. 22, 1841, p. 193.

[2] E. Carvallo, *Méthode pratique pour la résolution numérique complète des équations algébriques ou transcendantes*, Paris, 1896.

own paper it must be said that he cannot lay claim to any high degree of rigor, nor to precision in some of his statements.[1]

The Dandelin-Gräffe method has failed to attain popularity. In 1850 it was described by O. Berger in a historical paper.[2] In 1856 it is again described in a historical pamphlet.[3] In 1862 Martin Piller of the gymnasium in Dillingen brought out an exposition of the method.[4] He remarks in the preface that, thus far, no text-book of higher mathematics has included Gräffe's method. In 1865 P. C. Jelinek, S. J., in a publication which we noticed earlier, passed an adverse judgment upon it as involving too much computation. In 1879 it was greatly admired by Miguel Merino, of the observatory at Madrid, who translated Encke's memoir into Spanish. The most recent and for didactic purposes the ablest exposition of it is given by Gustav Bauer in his *Vorlesungen über Algebra*, Leipzig, 1903, XXIV. Kapitel.

We have never seen an account of the Dandelin-Gräffe method in English. Todhunter said in his *Theory of Equations*, London, 1880, p. 164: "There is no easy practical method of calculating the imaginary roots of equations at present known." Cayley says, in 1878, in the article "Equation" of the *Encyclopædia Britannica:* "Very little has been done in regard to the calculation of the imaginary roots of an equation by approximation." Either these writers did not have the Dandelin-Gräffe method in mind when they made these statements, or else they considered the method unsatisfactory.

Finding the Dandelin-Gräffe method too laborious, J. E. B. Valz[5] suggested in its place a method which consists in

[1]Thus, Carvallo says that, if the rth coefficients in the successive transformed equations fluctuate in *sign*, this fact discloses the presence of a pair of complex roots. See p. 16 of his paper. This condition is sufficient, but not necessary. The necessary and sufficient condition Carvallo does not state at all, namely that the coefficients shall fluctuate in *value*.

[2]O. Berger in *Programm des Gymnasiums zu Lemgo fuer das Schuljahr* 1849-50.

[3]M. F. Focke, *De aequationibus numericis superioris ordinis*, 1856, pp. 60-84.

[4]M. Piller, *Die Aufloesung der hoeheren numerischen Gleichungen durch successives Quadriren der Wurzeln*, Programm 1861-62, Dillingen, 1862.

[5]*Comptes Rendus*, Vol. 41, 1855, p. 685.

changing x to x^{10}, and then taking $x=1$. This suggestion has received no serious attention.

An achievement of considerable theoretical significance, at first sight far remote from the topic now under discussion, is that of Fürstenau[1] who in 1860 expressed any definite real root of an algebraic equation with numerical or literal coefficients, in terms of its coefficients. This is done through the aid of infinite determinants, a kind of determinants then used for the first time. In 1867 he extended his results to imaginary roots. If, instead of infinite determinants, finite ones are taken whose degrees are gradually increasing, one obtains approximations to the roots. The approximation is made to depend upon the fact that for high powers of the roots, the powers of all other roots become negligible in comparison to the power of the greatest root. It is here that the new method touches the older developments of Daniel Bernoulli, Euler, Fourier, Stern, Dandelin and Gräffe.

By a different path E. Schröder[2] arrived at an expression of which that of Fürstenau is a special case. Schröder showed that Fürstenau's expressions were closely related to recurring series, while Siegmund Günther[3] pointed out their relations to continued fractions. Günther's expressions apply to equations with literal coefficients as well, and yield a definite root, while Lagrange's method of continued fractions applied only to numerical equations and required that an approximate root-value be initially given. Günther explained Fürstenau's method in his *Lehrbuch der Determinanten.* A further discussion of Fürstenau is given by Hans Naegelbach in two articles.[4] In the first, Fürstenau's approximate values for the largest and smallest root, real or complex, are expressed

[1] Fürstenau, *Darstellung d. reell. Wurz. algebr. Gleich. d. Determinanten d. Coefficienten*, Marburg, 1860.

[2] *Math. Annalen*, Vol. II., 1870, p. 347.

[3] *Math. Annalen*, Vol. 7, 1874, pp. 262-268.

[4] *Archiv. d. Math. u. Phys.*, (Grunert), Vol. 59, 1876, pp. 147-192; Vol. 61, pp. 19-85.

by coefficients resulting from the division $1 \div f(x)$. These coefficients also can be made to reveal the amount of error in the approximation. Finally the case is considered when the maximum root is a multiple root. In the second paper the limiting value of the error is expressed by a series of successive approximate values of the roots themselves, on the supposition that the approximation is continued indefinitely. This value, known in practice only approximately, may be used in correcting the approximate root-values already found. Naegelbach illustrates his procedure by examples. Closely allied to the researches of Fürstenau and his followers is a paper by J. König[1] of Budapest on a general expression for the numerically least root of an equation.

5. THE METHOD BY INFINITE SERIES.

The extensions of the method of recurrent series in the solution of equations that were suggested by Fourier, stimulated a number of investigators. In the first place, Stern of Göttingen devoted much study to the solution of equations by continued fractions,[2] in continuation of the work of Lagrange, and to the solution by recurrent series which had been investigated by D. Bernoulli, Euler, Lagrange and Legendre.[3] Legendre had pointed out that by transformation of the equation, any root may become the largest, and consequently may be computed by recurrent series. But no short method of effecting this transformation presented itself. Fourier had suggested in his "exposé synoptique" a different scheme for arriving at all the roots, and this scheme, not actually worked out by him in his published works, Stern endeavors to reproduce. Stern shows that for large values of n, $\varphi_1 \varphi_2 = \left[(\Sigma \varphi_1^{n+1})^2 - \Sigma \varphi_1^{2n+2}\right] \div \left[(\Sigma \varphi_1^{n})^2 - \Sigma \varphi_1^{2n}\right]$, where φ_1 and φ_2 are the two largest roots, and φ_1 (the largest), can be found by the Bernoullian method. By dividing

[1] *Math. Annalen*, Vol. 9, 1876, pp. 530-540.
[2] *Crelle's Journal*, Vol. 10, 11, 1833-34.
[3] *Théorie des nombres*, 2e Ed., 1808, 1re partie, §XIV. p. 145.

$\varphi_1\varphi_2$ by φ_1 he obtains φ_2. Thus convergence to the required root is secured in all cases in which both roots are real or both imaginary. If φ_1 is real and φ_2 imaginary, then the process fails. Stern finds next $\varphi_1\varphi_2\varphi_3$ and divides this by $\varphi_1\varphi_2$ to obtain φ_3, and so on.[1] These results were mainly of theoretical interest; for practical computation the method of recurrent series is too elaborate.

Another research which involved attempts to retrace the steps of Fourier on recurrent series was that of C. H. Gräffe.[2] Then came papers on recurrent series by Mainardi,[3] C. G. J. Jacobi,[4] A. Laisant,[5] E. Schröder,[6] C. Runge[7] who made an extension to variable coefficients, and F. Cohn[8] who begins by studying the properties of quantities derived by recurrent processes and then applies his results to root-computation. Cohn obtains the exact conditions under which Bernoulli's process of computing the numerically largest and smallest root is valid.

It was shown by J. König[9] that Bernoulli's procedure is a special application of a general theorem relating to the behavior of certain functions of a complex variable on the circle of convergence.

Other recent studies on recurrent series are due to D'Ocagne[10] and A. Capelli.[11]

The solution of equations by the method of infinite series, which was a favorite subject of research during the eighteenth

[1] *Crelle's Journal*, Vol. 11, 1834, pp. 293-306. Stern's papers in Vols. 10 and 11 of Crelle's Journal were reprinted in book form at Berlin in 1834 under the title *Theorie der Kettenbruecke und ihre Anwendung.*

[2] *Auflosung d. hoh. numerischen Gleichungen*, Zürich, 1837, pp. 8-16. See also Gräffe in *Crelle's Journal*, Vol. 10, 1832, p. 288.

[3] *Ann. R. Lomb. Veneto*, 1839, p. 273, and Vol. 10, 1840, p. 113.

[4] *Crelle's Journal*, Vol. 13, 1835, p. 349.

[5] *Bull. des sciences math. et astr.*, 2e S., T. V., 1881, pp. 218-249.

[6] *Math. Annalen*, Vol. II., 1870, pp. 333-349.

[7] *Acta Mathematica*, Vol. VI., pp. 305-318.

[8] *Math. Annalen*, Vol. 44, 1894, pp. 473-475.

[9] *Mathematische Annalen*, Vol. 23, 1884, p. 447.

[10] *Journal de l'Ecole Polytechnique*, Vol. 64, 1894.

[11] *R. accademia d. scienze Fisich e Matem. di Napoli*, Fasciolo 7, 1895.

century, received considerable attention during the nineteenth. At the threshold of the new century some researches of the old type made their appearance which paid little attention to the question of convergence. In 1801 was published a paper by Pietro Franchini (1768-1837), a professor of mathematics at Rome, later at Lucques. This paper, entitled, *Sur la résolution des équations d'un degré quelconque,*[1] develops the roots into series which, for the special case $p-qx+rx^2-x^3=0$ yield the following expressions for the roots a, b, c: $a=p:q+rp^2:q^3-p^3:q^4+2r^2p^3:q^5-$etc., $b=q:r-p:q+q^2:r^3-p^2r:q^3-2p:r+$etc., $c=r-q:r+p:r^2-q^2:r^3+3pq:r^4-$etc.

In 1830 K. G. J. Jacobi[2] (1804-1851) explains a method of approximation by means of infinite series, depending upon a generating function and forming an extension of Cauchy's residual calculus. Cauchy[3] took up the solution by infinite series in 1837 and 1854.

The reversion of series was utilized in the solution of equations in 1846 by Valtinowsky.[4] In 1850 appeared at Giessen a pamphlet, entitled, *Die allgemeine Umkehrung der Reihen nebst Anwendung derselben auf die vollstaendige Lösung numerischer Gleichungen* by Ferdinand Kerz, "Rittmeister in der Gr. Hess. Gendarmerie." The author goes into minute detail on the reversion of series and claims to have elaborated a complete practical solution by series of equations of all degrees up to and including those of the sixth degree, and thereby to have pointed out the mode of procedure for equations of any degree. He explains the reversion in great minutia. "If thereby the limit of practical usefulness is overstepped," he says, "then may this find its excuse in the difficulty of defining that limit." His contention that a com-

[1] *Mémoires de l'acad. d. scien. de Turin,* année 1792 a 1800, Tom. VI., Turin 1801, Pt. II., p. 115-126.

[2] *Crelle's Journal,* Vol. 6, 1830, p. 257.

[3] *Comptes Rendus,* Vol. IV., 1837, pp. 216, 362, 612, 773, 805; Vol. V., p. 301, 357; 1854, 1er sem. p. 1104. *Jour. Ecole Polytech.,* Vol. 15, 1837, p. 176.

[4] *Crelle's Journal,* Vol. 33, 1846, p. 164.

binatorial presentation of the reversion has no value probably has reference to the work of the combinatorial school in Germany at the close of the eighteenth century which claimed by the reversion of series to have reached a general solution of equations.[1]

We meet with other attempts to overcome the practical difficulties surrounding the process of reversion of a function. Thus, in an article *On General Numerical Solution*,[2] W. S. B. Woolhouse determines the inversion of a given function in a series less diffuse than the one usually given under reversion of series, and involving the values of the differential coefficients for an approximate value of the variable. The article is followed by a note of De Morgan who reaches the results of Woolhouse by a different route. Woolhouse gives several examples, one on the computation of interest in annuities.

In a treatise *Die allgemeine Umkehrung gegebener Funktionen*, 1849, Oscar Schlömilch (1823-1901) maintains that none of the methods of reversion of series, based upon the theory of combinations, are practically applicable and that even Lagrange's formula labors under this defect. Schlömilch then proceeds to develop methods of reversing a given function by Fourier's series and by definite integrals. It was maintained in 1883 by J. G. Hagen,[3] then of Prairie du Chien in Wisconsin, that though theoretically elegant, Schlömilch's methods are not preferable when it comes to the actual computation of the numerical values of the coefficients of the reversed series. Hagen gives the recurring formula for the computation of the coefficients of the reversed series a more convenient form and then applies the same to numerical equations.

The solution in infinite series was suggested in 1855 by

[1] Johann Friedrich Pfaff, *Tractatus de reversione serierum sive de reversione aequationum per series*, which is part of Pfaff's *Disquisitiones analyticae*, Helmstädt, 1797.

[2] *Proced. London Math. Soc.*, Vol. II., 1868, pp. 75-84.

[3] J. G. Hagen, "On the Reversion of Series and its Application to the Solution of Numerical Equations," *Proceed. American Phil. Soc.*, Vol. 21, p. 883, p. 93.

Thereim,[1] in 1857 by Fergola,[2] in 1859 by Valz,[3] in 1875 by L. W. Meech[4] in two articles which contain also a proof and an extension of Descartes' Rule of Signs. Another solution by series is given by J. B. Mott,[5] and by Artemas Martin.[6]

It cannot be said that the publications hitherto set forth found a mode of securing the roots of numerical equations by the method of infinite series that is satisfactory to the practical computer.

Hardly more successful was A. Heegmann[7] who issued memoirs in 1861 and 1866; or Ch. Méray[8] who, in an able paper, proves the existence of roots by showing how the roots may be actually computed by the aid of series; or Axel Söderblom who in 1899 wrote at Gothenburg, Sweden, on the *Résolution numérique des équations algébriques.*

In the Dandelin-Gräffe method we saw that the roots were obtained all at one time. This simultaneous calculation of all the roots came to be achieved also by the method of infinite series. For a three-term equation this was achieved in 1883 by R. Dietrich[9] and in 1887 by P. Nekrasoff.[10] For the general equation it was accomplished by Emory McClintock of New York in a very noteworthy article entitled, *A method for calculating simultaneously all the roots of an equation.*[11] By his Calculus of Enlargement he obtained series better adapted for computation than those given by Lagrange, whose method appears as a special case of that of

[1] *Crelle's Journal*, Vol. 49, 1855, p. 187, 242.

[2] *Ricerche sulla risoluzone per serie*, Napoli, 1857.

[3] "Essai de la résolution des équations par les séries et les logarithmes," *Comptes Rendus*, Vol. 49, 1859, p. 750.

[4] *The Analyst*, (Des Moines, Iowa), Vol. 2, 1875, pp. 81-88, 97, 104.

[5] *Analyst*, (Des Moines, Iowa), Vol. 9, 1882, pp. 104-106.

[6] *Our Schoolday Visitor, Math'l Annual*, 1871.

[7] A. Heegmann *Essai d'une nouvelle méthode de résolution des équations algébriques au moyen des séries infinies*, Paris, 1861; *Résolution générale des équations*, Paris, 1865.

[8] *Bulletin des Sciences Math.*, 2e série, T. 15, 1891, p. 236.

[9] *Archiv der Math. u. Phys.*, Vol. 69, p. 337.

[10] *Mathematische Annalen, Vol.* 29, 1887, p. 413.

[11] *American Journal of Mathematics*, Vol. 17, 1895, pp. 89-110.

McClintock. The series used by McClintock may be derived, as he himself points out, by applying "Lagrange's series," and without the use of the Calculus of Enlargement. A prominent part in McClintock's treatment is his theory of "dominant" coefficients, which theory lacks precision, inasmuch as no criterion is given to ascertain whether certain coefficients are dominants or not, which is both necessary and sufficient. It was shown in 1903 by Preston A. Lambert of Lehigh University[1] that the expansions obtained by Lagrange's series may be obtained more easily by a direct application of Maclaurin's series. In 1908 Lambert published two additional articles on the solution in infinite series,[2] in which careful attention is paid to convergency conditions. He shows that the convergency conditions for a t-term equation can be set up when those of a $(t-1)$-term equation are known. The process employed by Lambert, of breaking up an equation into two parts and then introducing as a factor a parameter into one of the two parts, is one which seems to have been used first by Cauchy in one of the articles of 1837, to which reference has been made above.

The general solution of algebraic equations by Maclaurin's formula, yielding power series of the coefficients, was studied by C. Rossi,[3] who reaches results of which those of Lambert, published in 1903, for the trinomial equation, are special cases. Rossi's article was the starting point of an extended note on this subject, published in 1907 by A. Capelli.[4]

These recent researches of American and Italian mathematicians have placed the determination of real and imaginary roots of numerical equations by the methods of infinite series within reach of the practical computer. The methods

[1] *Proceed. American Philosophical Society*, Vol. 42, 1903, No. 172.

[2] *Proceed. American Phil. Soc.*, Vol. 47, 1908, p. 111; *Bull. Am. Math. Soc.*, 2nd S. Vol. 14, 1908, pp. 467-477.

[3] *Giornale di matematiche di Battaglini*, T. 44, (1906), pp. 279-290.

[4] *Rend. d. R. Accademia d. scienze Fisiche e Matem. di Napoli*, Fascicolo 5° a 11°, 1907.

themselves indicate the number of real and of imaginary roots, so that one can dispense with the application of Sturm's theorem here just as easily as one can in the Dandelin-Gräffe method.

6. SOLUTIONS OF THE TRINOMIAL EQUATION AND THEIR EXTENSIONS TO OTHER EQUATIONS.

Trinomial equations are of particular interest and importance. Many researches are especially devoted to them. For that reason it seems best to group these investigations under one head, even though many of them really belong under some previous head, if the classification according to the method employed in their solution were rigidly adhered to.

Trinomial equations were the subject of special study during the eighteenth century. Among the first to give attention to this subject in the nineteenth century was Dandelin, who, in the third supplement to his paper of 1826,[1] discusses trinomial equations and Kepler's problem. We have seen that this paper was completely overlooked by the mathematicians of his day.

The use of logarithms of sums and differences in the solution of equations was first suggested in connection with quadratic equations by Gauss in the Tables of Vega and Hülsse in 1840, and again in 1843 in a letter to Schumacher, wherein Gauss shows their use in solving the cubic which in parabolic motion serves to determine the true anomaly,[2] and remarks that all trinomial equations can be similarly solved. This last fact was not developed by him publicly until 1849,[3] when he read before the Königl. Gesellschaft der Wissenschaften a paper, *Beitraege zur Theorie der Algebraischen Gleichungen*, the first part of which discusses his famous

[1] *Nouveaux mémoires de l'académie roy. d. scien. et bell. de Bruxelles*, T. 3, 1826, pp. 7-71.

[2] Gauss' *Werke*, Vol. III., 1876, p. 255; Vol. VI., 1874, p. 191; *Astronomische Nachrichten* Nr. 474; R. Mehmke in *Zeitsch. f. Math. u. Phys.* (Schlömilch), Vol. 35, p. 180

[3] Gauss' *Werke*, Vol. III., p. 85.

proof of 1799 that every equation has a root, and the second part of which takes up the solution of numerical equations. He remarks first that real as well as imaginary roots of trinomials can be solved by infinite series, that in the case of nearly equal roots the convergence is very slow, and in the limiting case of equal roots it is slower than in any converging geometric progression, that indirect methods of solution are preferable except when the convergence happens to be very rapid. Gauss considers $x^{m+n} \pm ex^m \pm f = 0$. Instead of logarithms of sums and differences (which were first suggested by Lionelli and are often called "Gaussian logarithms)," ordinary logarithms may be used, he says, though less advantageously. Proceeding to imaginary roots, Gauss remarks that they are ordinarily harder to find, because they must be gotten from an infinite realm of two dimensions, instead of only one, but shows that in case of trinomials even with imaginary coefficients, a procedure can be followed which sets the problem into the realm of one dimension. Expressing the imaginaries in the form $r(\cos p + i \sin p)$ he gets, by equaling the reals and the imaginaries, two equations from which he eliminates r thereby obtaining a convenient expression for finding p. From p the value for r follows easily.

The use of logarithms of the sums and differences in connection with trinomial equations was explained in 1846 in Italy by Bellavitis.[1]

In England trinomial equations were solved for imaginary roots by the use of logarithms, and the method of double false position, in an article written by Thomas Weddle.[2]

In America, a method involving the use of logarithms, of solving cubic equations having three real roots of which two may be equal, was given in 1878 by L. G. Barbour[3] of Richmond, Kentucky. Five years later he extended his method to the complete solution of cubics with two imaginary roots.[4]

[1] *Memorie dell'I. R. Istituto Veneto di scienze*, etc., Vol. III., 1846, p. 110.
[2] *The Mathematician*, Vol. III., 1849, pp. 285-289.
[3] *Analyst* (J. E. Hendricks), Vol. 5, 1878, pp. 73-79.
[4] *Analyst*, Vol. 10, 1883, pp. 115-120.

Using "Gaussian logarithms," Andr. Kjeldgaard[1] approximates to the roots of trinomial equations of the type $x^n+px+q=0$, by the formula $y_{r+1}=\sqrt[n]{ay_r+a}$, the equation being first changed to the form $x^n-ay-a=0$. A somewhat more general treatment of trinomial equations by "Gaussian logarithms" was given in 1890 by the Hon. Lord M'Laren.[2]

Gauss' method of solving trinomial equations is explained by A. M. Nell,[3] who adjusts the mode of procedure to the new tables of logarithms for sums and differences.

The extension of Gauss' method to quadrinomials was undertaken in 1884 and 1885 by S. Gundelfinger,[4] who establishes criteria for the number of real roots and gives rules for the quick recognition of the first approximations to the roots. Such criteria for real roots were also given in 1889 by Carl Faerber.[5] The extension of Gauss' results to quadrinomial equations was given by Alfred Wiener in an article which captured a prize offered on this subject.[6] The extension of Gauss' results to any equation was taken up by R. Mehmke, professor in Darmstadt, who published in 1889 a logarithmic-graphic method of solving numerical equations,[7] and in 1891 a more nearly arithmetical method of solution by logarithms.[8] Mehmke shows how either kind of logarithms may be used. The method is essentially a mixture of the Newton-Raphson method and the regula falsi, as regards its theoretical basis. Instead of using the differential calculus in the computation of the increment h of the approximate root-

[1] *Tidsskrift for Mathematik*, Kopenhagen, (4) Vol. IV., 1880, pp. 135-137.

[2] *Proc. of the R. Society of Edinburgh*, 1891, pp. 270-280.

[3] *Archiv d. Math. u. Phys.*, 2 S., Vol. I., 1884, pp. 311-333.

[4] See Mehmke, *Zeitschr. fuer Math. u. Phys.*, Vol. 36, 1891, p. 180.

[5] C. Färber, *Herleitung fuer die Anzahl reeller Wurzeln von Gleichungen (speciell der allgemeinen viergliedrigen und der Gleichungen fuenften Grades.)* Inaugural *Dissertation*, Berlin, 1889.

[6] *Zeitschr. f. Math. u. Physik*, Vol. 31, 1886, pp. 65-87, 192.

[7] *Civilingenieur*, Vol. 35, 1889, p. 617.

[8] R. Mehmke, "Praktische Methode zur Berechnung der reellen Wurzeln reeller algebraischer oder transcendenter numerischer Gleichungen mit einer Unbekannten," *Zeitsch. f. Math. u. Phys.*, Vol. 36, pp. 158-187.

value x_0, Mehmke effects this computation by proportional parts as in logarithmic interpolation. If x_0 be assumed to increase by an amount h, then he computes by interpolation, step by step, the changes in every term of $f(x_0)$ and thus the change in $f(x_0)$ itself. Suppose $f(x_0)=R$, and $f(x_0+h)=R+Sh$. If x_0+h is to be a root, we must have $R+Sh=0$, which yields a value h as a correction of x_0. Mehmke's method is a repetition of this process, carefully worked out in its mechanism to satisfy the wants of practical computers. Unlike the great mass of writers of numerical equations, Mehmke pays careful attention to the algorithm. The initial value of x_0 he determines graphically. Well-known is Mehmke's article on methods of computation in the *Encycklopaedie der Mathematischen Wissenschaften*, Vol. I. p. 938. There, and in all his articles he shows a strong leaning toward graphical and mechanical processes of computation.

Returning to earlier modes of dealing with trinomial equations which do not depend upon the use of logarithms, we refer first to a method due to Rutherford[1] for finding the three roots of a cubic which is neater than the methods that he had explained in his earlier publication. He finds the real root r by Horner's method, then the other two roots, $\varphi+\sqrt{\beta}$ and $\varphi-\sqrt{\beta}$, whether real or imaginary, are deduced very simply from r and the coefficients of the given and transformed equations, without solving any quadratic equation.

Special methods of computing the real roots of quadratics and cubics have been published also by J. Odstrčil of Bohemia.[2]

By infinite series the solution of trinomials was carried out by A. Gebhardt, using a table depending upon gamma functions.[3]

A. S. Guldberg disposes of the numerical solution of cubic equations in this wise:[4] By linear substitution he brings the

[1] *The Mathematician*, Vol. 2, 1850, pp. 257-259.
[2] *Jahrbuch ue. d. Fortschritte der Math.*, Vol. 10, 1878, pp. 61-63.
[3] *Die Auflös. dreigliedrig. Gleich. durch Reihen*, Leipzig, 1873.
[4] *Vidensk. Selskabets Forhandl.* i Christiania, 1871.

cubic to the form $x^3-cx-c=0$, and then uses a seven place table which he constructed, and which gives at once the value of x corresponding to a given value of c. A similar table is constructed for the quintic $x^5+ax+b=0$. A table of the same character, but not so extensive, was published a few years later by F. Burnier.[1] In 1877 J. J. Åstrand of Bergen, outlined a solution of the trinomial equation, $x^n-ax\pm b=0$[2], and in 1882 gave a method of approximation to the roots of $x^n\pm ax\ \pm b=0$.[3] Infinite series for the roots of $x^m+ax^n=b$ were obtained in 1879 also by Julius Farkas of Polgárdi in Hungary.[4] In 1880 S. Günther, in an article rich in historical notes, extended Åstrand's expression for $x^n-ax\pm b=0$, to the more general form $x^{m+n}+ax^m=b$,[5] which was discussed by v. Schaewen[6] in connection with a life insurance problem in interest.

With the aid of indeterminate coefficients, von Mangoldt[7] arrived at an expression of the roots of a trinomial equation by infinite series, in a dissertation of 1878. In 1883 R. Dietrich arrived at results for trinomials similar to Åstrand's of 1877, in a paper[8] which treats the general problem of algebraic equations by infinite series. The series are deduced from Taylor's theorem by substitution and they represent a single root or several roots.

In 1886 W. Heymann showed how to express the roots of trinomial equations in terms of definite integrals.[9]

Trinomial equations are treated in a novel way by the Russian, P. Nekrassoff,[10] who develops some interesting geo-

[1] *Bull. de la Société Vaudoise d. sciences nat.*, Lausanne, Vol. X.

[2] *Astron. Nachrichten*, No. 2134.

[3] *Archiv for Math. og Naturv.*, Vol. VI., 1881-1882, pp. 448-459.

[4] *Grunert's Archiv*, Vol. 64, 1879, pp. 24-30.

[5] *Zeitschr. f. math. u. naturw. Unterricht*, Vol. XI, 1880, pp. 68-72, 267.

[6] *Loc. cit.* p. 264.

[7] Von Mangoldt, *Ueber die Darstellung der Wurzeln einer dreigliedrigen algebraischen Gleichung durch unendliche Reihen*, Berlin, 1878.

[8] *Archiv der Math. u. Physik*, Vol. 69, 1883, pp. 337-381.

[9] *Math. Annalen*, Vol. 28, pp. 61,-80; *Zeitsch. fuer Math. u. Physik*, Vol. 31, pp. 223-240.

[10] *Math. Annalen*, Vol. 29, 1887, pp. 413-440.

metric relations and then proceeds to study the convergence of series expressing powers of the roots, wherein he connects with the work of Heymann and of Westphal.[1]

E. Netto[2] considers $x^n-x-a=0$ and $x_{k+1}=\sqrt[n]{x_k+a}$, and proved what used to be assumed outright, namely, that with increasing k, x_k approaches a real root of the equation. This paper, as well as one by K. E. Hoffmann[3] are further discussed and generalized by C. Isenkrahe.[4]

A neat procedure for computing the roots of a cubic, digit by digit, by simple successive transformations of the given equation according to the scheme $x=r+r'\div 10$, is explained by H. Dörrie.[5]

7. MISCELLANEOUS RESEARCHES.

Under this head we group a number of publications which did not seem to fall naturally into the groups of topics previously considered. We begin with a new method of finding near values of the roots of algebraic equations having terms alternately plus and minus, given in 1812 by Charles Hutton.[6] In $x^3-px^2+qx-r=0$, he assumes $x=a$ and gets $x^3-3ax^2+3a^2x-a^3=0$. Letting $3a=p$, $3a^2=q$, and $3a^2x-a^3=qx-r$, he eliminates a and solves for x in terms of p, q, and r. This, he says, gives approximately the middle root, if real. Later in the article Hutton modifies his scheme by taking $3ax^2+a^3=px^2+r$ and eliminating a, as before. He extends the method to the quartic and remarks that it might be extended to equations of higher degrees.

No less curious a process is developed by A. Timmerans[7]

[1] Westphal. *Evolutio radicum aequationum algebraicarum eternis terminis constantium in series infinitas*, Gottingae, 1850.

[2] Netto, "Ueber einen Algorithmus zur Auflösung numerischer algebraischer Gleichungen" in *Math. Annalen*, Vol. 29, 1887, p. 141.

[3] "Ueber die Auflösung der trinomischen Gleichungen durck Kettenbruchähnliche Algorithmen" in *Archiv fuer Mathematik*, Vol. 66, 1881, pp. 33-46.

[4] *Math. Annalen*, Vol. 31, 1888, p. 309.

[5] *Archiv der Math. u. Phys.*, 3 S., Vol. 11, 1907, pp. 168-173.

[6] *Tracts on Mathem. and Philosoph. Subjects*, Vol. I., London, 1812, p. 218.

[7] *Correspondance math. et phys.* (Gaud), T. II., 1826, pp. 218-220.

of Gand who uses a formula for approximating more closely to a root, which agrees with the one used in the Calculus in finding the x-coördinate of the center of curvature of a curve.

We have seen that the rule of two false positions was used in the solution of affected equations before the time of Vieta. It is a curious fact that since the time of Vieta, during the seventeenth and eighteenth centuries, this method was seldom described, but that it appears again during the nineteenth century. As some one has remarked, the history of some scientific subjects resembles a river which sinks underground in a part of its course and emerges again at a distant spot, swelled perhaps by certain subterranean tributaries. In school books of the nineteenth century the method of double false position is frequently given for the solution of equations. At this time we have also seen it brought into alliance with other methods. Occasionally special papers are given to its elucidation and further development. A pamphlet published in 1847 at Carlstad by C. A. Agardh[1] describes a mode of solution which is essentially the method of two false positions. A generalization of the *regula falsi*, as this method is sometimes called, was given by M. Lerch.[2]

Finding that Budan's procedure was not well adapted for close approximations, Louis Olivier[3] suggested in 1827 an approximation by the aid of formulae of interpolation, particularly Lagrange's. In the same journal Olivier[4] gave criteria for the number of real roots, in amplification of Descartes' rule. Interpolation as a method in the approximate solution of equations was discussed also by Bellavitis,[5] who refers to simplifications suggested by the astronomer Encke. In 1852 A. F. Möbius published some formulae based on

[1] *Sur une méthode élémentaire de résuodre les équations numériques d'un degré quelconque par la sommation des séries*, Carlstad, 1847.

[2] *L'enseignement mathématique*, T. VII., 1905, p. 303.

[3] *Crelle's Journal*, Vol. II., 1827, pp. 214-216.

[4] *Crelle's Journal*, Vol. I., 1826, pp. 223-227.

[5] *Memorie dell 'Istituto Veneto di scienze*, Vol. III., 1846, Nota IV., p. 106; Vol. VI., 1857, p. 3; 1860, p. 202.

Lagrange's interpolation formula and also the process of false position.[1]

A doctor of medicine, J. Brizard, published in 1834 at Paris and Besançon a pamphlet bearing the title *Nouvelle méthode pour la résolution des équations numériques de tous les degrés*, which embodies some of the features of Budan and Stevin.

A method somewhat analagous to that of Newton, except that the value of z in $x=r+z$ is taken as the arithmetic mean of two differently derived estimates of z, is given by A. F. Vogel[2] of Leipzig in 1845. Vogel brings continued fractions into service. The method is vitiated through the employment of an unsafe criterion for imaginary roots.

In 1890 R. Mehmke communicated, without proof, a scheme for developing roots of algebraic equations in the form of periodic continued fractions.[3]

The *Resolution of Equations by means of inferior and superior limits* was published by James Lockhart in London in 1842. The given equation is transformed, so that the required root lies between 1 and 0. Let r be the absolute term of the transformed equation, and q the greatest coefficient whose sign is contrary to that of r. Consider q and r as positive. Then the least root of the equation is greater than $r \div (q+r)$. A similar expression is obtained as a superior limit of the required root. The approximation is secured by the application of these limits to the successive transformed equations. Lockhart interested himself in the theory of numerical equations during many years and published several other papers.[4]

[1] A. F. Möbius, *Gesammelte Werke*, Vol. 4, Leipzig, 1887, "Beitrag zur Lehre von der Auflösung numerischer Gleichungen."

[2] *Entdeckung einer numerischen General-Auflosung aller hoeheren endlichen Gleichungen von jeder beliebigen algebraischen und transcendenten Form*, Leipzig, 1845. According to L. A. Sohncke's *Bibliotheca Mathematica*, 1854, p. 133, Vogel's monograph was brought out in 1845 in Leipzig, in three languages: German, French and English.

[3] Böklen's *Mitteilungen*, Vol. III., pp. 9-14.

[4] See James Lockhart, *A Method of Approximating toward the Roots of Cubic Equations*, London, 1813; *Extension of the Celebrated Theorem of C. Sturm*, Oxford, 1839; *The Nature and roots of Numerical Equations*, London, 1850.

About the same time appeared in Germany a pamphlet by G. A. Jahn,[1] purporting to find all roots from their limits.

Philip Beecroft's *General Method of finding all the roots, both real and imaginary, of Algebraical Equations*, Hyde, 1854, contains two methods of solving equations by approximation which deserve notice, notwithstanding the fact that the author claims to have found an algebraic solution of the general quintic. His first method consists of approximations to a quadratic factor of the equation, which can be made without a previous knowledge of the nature of the roots. In Beecroft's second method, let r be an approximate root. Take $x=r+rx_1$, then in the equation for x_1 find r_1 as a value near x_1. Put $x_1=r_1+r_1x_2$. Find r_2 close to x_2, and so on. One has then $x=r+rr_1+rr_1r_2+\ \ldots$ No inquiry is instituted to ascertain whether these methods will always succeed.

The method of differences, which we first encountered in 1669 in a paper by Collins and a little later in the writings of De Lagny, is explained occasionally in nineteenth century publications. It is given, for instance, by Bellavitis in his historical memoir and by J. A. Serret in his *Cours d'algèbre supérieure.*

A method of transformation of an equation which consists in making the left member a perfect nth power, was explained briefly in 1859 by Dascom Greene of the Rensselaer Polytechnic Institute.[2] In $x^3+2x^2+3x=13089030$, he obtains $x+1=\sqrt[3]{13089031+x^2}$, and neglecting x^2, $x+1=236$, nearly. Hence $x=235$. Take $x=200$ and obtain a closer value, and so on.

A paper based upon geometric considerations was published in 1861 by A. Vallas[3] of Alexandria in Louisiana. Vallas shows that approximations may be obtained by abscissas of parabolic arcs tangent to the curve of the given

[1] G. A. Jahn, *Leichte u. sichere Methode saemmtliche Wurzeln einer hoeheren numerischen Gleichung aufzusuchen und zu berechnen*, Leipzig, 1844.

[2] *Mathematical Monthly*, (J. D. Runkle), Vol. I., 1859, pp. 406-408.

[3] *Mathematical Monthly*, (J. D. Runkle), Vol. III., 1860-61, p. 10.

equation where the curve intersects the axis of the ordinates. We take this author to be the Anton Vallas who brought out in 1843 in Vienna a monograph, *Beitrag zur Auflösung der höheren Gleichungen.*

A cognate idea is embodied in a paper by I. B. Favero. Devoting his attention mainly to transcendental equations, Favero[1] in 1875 points out that, if one takes the greatest and least value, within a given interval of the variable, of the simple functions x^λ, sin x, tan x, etc., one can also compute a maximum or minimum value, for that interval, of composite functions involving these simple ones; by breaking the interval up into smaller ones, the real roots may be separated, and approximations to the roots may be reached by considering certain two parabolas touching each other and touching also the curve of the function. The intersections of the parabolas with the axis of x supply the approximate values. The method is illustrated by several interesting examples.

H. F. Talbot in 1875 described, in a curious and most interesting *Essay toward a General Solution of Numerical Equations of all Degrees having Integer Roots,*[2] a method of solution founded upon the "casting out of the nines." "It consists in substituting for any number the remainder which that number leaves when divided by *nine.*"

Of little value is A. Otto's *Das grösste Problem der Rechenkunst gelöst,* Berlin, 1894, which proceeds by the method of trial and error. Along the same line is a booklet published in 1900 in London, from the pen of M. A. McGinnis of Neosho in Missouri, under the title: *The Universal Solution of Numerical and Literal Equations.* The author gives numerical approximations by the method of trial and error which are often ingenious, but the book as a whole discloses a complete misunderstanding of the question at issue in the algebraic solution of equations.

[1] *Giornale di Matematiche* (G. Battaglini), Vol. XIII., 1875, pp. 249-282.
[2] *Transactions Roy. Soc. Edinburgh,* Vol. 27, pp. 303-312.

8. SUMMARY.

1. Limits superior to all the roots are proposed by Bret, Vène, Thibault, Laguerre; inferior limits are given by Fouret.

2. For the detection of complex roots provisional theorems are given by Fourier and Budan. Then follow the great theorems of Sturm, Cauchy and Laguerre on the exact number and location of real and complex roots.

3. Fourier and Dandelin discover conditions for using the Newton-Raphson method with safety.

4. Fourier's book of 1831 is read by mathematicians in all European countries. The more important commentaries upon it are those of Stern and J. R. Young.

5. Numerous commentaries on the Newton-Raphson method appear, more especially in France, which have for their object: (*a*) The use of approximations of higher degrees than the first; (*b*) Means for the easier detection of the degree of approximation reached at any stage; (*c*) Affiliation with the regula falsi or other methods; (*d*) The discovery of safe conditions of using the method that are less restricting than Fourier's conditions.

6. Cauchy extends the Newton-Raphson method to the computation of complex roots.

7. France is the only country where the Newton-Raphson method has held almost undisputed sway.

8. The Ruffini-Horner process is invented by Ruffini in 1804, but failing to become known, it is rediscovered by W. G. Horner in 1819. This is the best didactic method for young students. It has been used widely in England and the United States; less widely in Germany, Austria and Italy; and not at all in France.

9. A second paper of Horner was published in 1830, a third in 1845.

10. The Ruffini-Horner process was extended so as to

yield approximations to complex roots by Rutherford, Bellavitis, Spitzer, Jelinek and Mor.

11. Analogous to the Ruffini-Horner method is that of Weddle. It was re-invented by Giesen and extended to complex roots by Spitzer.

12. The Dandelin-Gräffe method, dispensing with all preliminary tests on the nature and location of the roots, and yielding all the roots simultaneously, is invented by Dandelin, but being overlooked, it is re-invented by Gräffe. The exposition of it is improved by Encke and Carvallo. It is not widely used.

13. Of theoretic interest is Fürstenau's solution by infinite determinants.

14. The method of recurrent series, studied by Legendre, Fourier, Stern, and others, is not a practical method.

15. The solution in infinite series is studied by a large number of mathematicians. The most decisive advances recently made in America and Italy render the method of marked practical value. It is able to proceed without preliminary tests on the nature and location of roots and to supply all the roots simultaneously.

16. Gauss solves trinomial equations by logarithms. The method is extended by Mehmke and others to quadrinomials and the general equation. Many papers are written on trinomial equations.

17. Methods of solving affected equations by two false positions, which were first used before the time of Vieta, but were seldom mentioned during the seventeenth and eighteenth century, are revived in the nineteenth century and are frequently found in school books.

9. GENERAL REMARKS.

In a patent office are seen wonderful exhibits of drawings and models. The most diversified ideas are called into play by different inventors for the accomplishment of one and the

same end. In fact, it looks at times as if the number of possible inventions for the achievement of one and the same object was without limit. But upon closer study of the drawings and models, one finds that in this richness of design there are after all only a very few which combine all the qualities which constitute a great invention or that find wide acceptance among the people as labor-saving devices. Some inventions, though very ingenious, do not cover a sufficiently wide range of operations, others lack that extreme simplicity which is a prerequisite for popularity. Still others, though based on novel ideas, are not worked out with sufficient attention to detail or, perhaps, fail to operate with safety and certainty. Others again appear to have served merely the purpose of affording the inventor some intellectual gymnastics and mental amusement, and are exhibited merely to gratify the curious.

The history of the solution of numerical equations is such a curiosity shop. In it we find all the types of inventions named above, and more. We find the methods of didactic value in the instruction of the young and inexperienced operator. We find others of complicated mechanism serviceable only to the highly trained mathematician. We find some excellent devices that are, however, applicable only to equations of a certain number of terms or of a certain degree. Others sometimes labor under the defect of leading the operator to wrong inferences or of leading him backwards or forwards without converging to results. Some do not give the computor all the information he may need, while others are hardly practical unless the operator desires to ascertain all the roots, both real and imaginary. Different devices are fitted to the various temperaments of computers. Some prefer to ascertain a root by easy steps, digit by digit; others have a fondness of combining several steps into one single, though much more laborious step.

Notwithstanding the multifarious efforts put forth during

the last few centuries, there is reason to think that the end of research in this field of inquiry is not yet. At present there exists no general theory of approximation to the roots. The various theorems that have been formulated have not been brought into organic relation to each other so as to impart to the subject as a whole the character of a mathematical theory. Nor have general points of view been reached, from which all the special methods now known appear in their natural relation as special cases. It is not to be inferred, however, that nothing has been done along this line. In the researches which cluster around the Newton-Raphson method it has been the custom since the time of Fourier to speak of approximations of the first degree, the second degree, and of even higher degrees. This classification indicates a broader point of view. One research which marks a long step in the direction of a general theory was published in 1870 by E. Schröder, under the title: *Ueber unendlich viel Algorithmen zur Auflösung der Gleichungen.*[1] This writer endeavors to consider different methods of approximation to the roots of numerical equations from a common point of view, embodied in the following theorem: Let $f(z)=0$ be the given equation, z one of its roots, let also $F(z)$ be a single-valued function within a region surrounding z which has the property that makes $F(z)=z$, then one may put $z'=F(z)$, $z''=F(z')$, $z'''=F(z'')$, and so on, and thereby obtain an approximation to z, provided *mod.* $F'(z)$ is less than unity. The approximation is of the nth order, if the first $n-1$ derivatives of $F(z)$ are zero. The initial approximation z' must lie within a certain range of z, but the limits of this range have not yet been fixed.

That a final development of methods has not yet been reached is evident also from the fact that wide disagreement exists as to the relative merits of the different methods. The territory, being as yet only partially reconnoitered, affords

[1] *Mathematische Annalen*, Vol. II., 1870, pp. 317-363.

no common viewpoint. One man starts from the valley and, ascending the mountain side, gets an expanding view; another descending from the mountain top, gets a contracting view. After the territory shall have been more thoroughly studied, greater unanimity will prevail, but differences in individual temperament will probably never permit complete unanimity.

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No. 8. The Succession of Plant Life on the Gravel Slides in the Vicinity of Pike's Peak . . *Edward C. Schneider.*

No. 9. The History of Colorado Mammalogy. *Edward R. Warren.*

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THE SUCCESSION OF PLANT LIFE ON THE GRAVEL SLIDES IN THE VICINITY OF PIKE'S PEAK.

By Edward C. Schneider.

The granite core of the Rocky Mountains has been uncovered over the greater part of the mountains of the Pike's Peak neighborhood and is now exposed to the consequences of weathering. This granite is readily disintegrated and decomposed into pieces, large and small, which fall away from boulder and cliff faces. This debris may accumulate near the parent rock or roll and slide for considerable distances down the mountain's side, and is continually being reduced by the forces of disintegration and decomposition to the smaller particles of the irregular talus or of the more homogeneous gravel slide. Into such new soils plants soon migrate, helping along the process of decomposition, at the same time binding the particles of gravel more or less firmly together, and thus they produce conditions more favorable for their offspring and other forms of plant life. A study of the changes in the physical conditions on these gravel slides and of the more important phases of the succession of plant life on them constitute the subject matter of this paper.

The gravel slides in the immediate vicinity of Pike's Peak have been considered up to an altitude of 9000 or 9500 feet. Much of the work recorded was carried on near Crystola in Teller County, Colorado, situated on the Colorado Midland Railroad, and along the Colorado Springs and Cripple Creek Railroad. The most extensive naked gravel slides occur along the last named railroad. The later stages of the plant succession are equally good along both roads.

The Perfect Succession.

Professor F. E. Clements in "Research Methods in Ecology" indicates seven stages in the talus (gravel) suc-

cession of the Rocky Mountains. The normal sequence of these is (1) the crustose lichen formation; (2) the foliose lichen formation; (3) the gravel slide formation in which the pioneer xerophytic spermatophytes enter and prepare the soil for the next; (4) the half gravel slide formation which is a grassland stage. This is followed by (5) the thicket formation which is succeeded by (6) the pine forest formation (dry pine stage—*Pinus xerohylium*), and this gives way to the ultimate and stable condition (7) the spruce forest formation. This series accounts for each stage that may occur in the perfect primary succession in the Pike's Peak region. However, the succession does not always follow the perfect course, frequently one or more of the normal stages may be suppressed or entirely omitted. The succession may terminate on some mountain slopes at the thicket or dry pine stages as well as with the spruce forest.

IMPERFECTIONS OF THE SUCCESSION.

The boulders of the irregular talus are frequently lichen covered, but the typical gravel slide with its more uniform particles does not often present well developed lichen stages. On slopes where movement is still in progress little or no lichen is to be found. Only where the angle of the slope is moderate and the gravel has been undisturbed for a long period does the foliose lichen occur abundantly. The crustose lichen is more rarely present.

Frequently the grassland or the half gravel formation and the thicket stage are very much suppressed and even may occasionally be entirely omitted (see figure 1.) On such slopes excellent examples of the typical gravel slide formation occur and in this the yellow pine, *Pinus scopulorum* (Engelm.) Lemmon, and more rarely the white pine, *Pinus flexilis*, James, are found establishing themselves. The trees at first are very widely separated. Invasion is intermittent and occurs only at long intervals, the difficulty experienced

in establishing the seedling is evidenced by the very few individuals that succeed. Almost never does a clump of these pines occur, the trees of all ages being far separated. When grasses appear in this abbreviated succession they are only such as normally enter in the older gravel slide formation. The kinnikinic, *Arctostaphylos uva-ursi* (L.) Spreng, enters sometimes. The thicket omission is suggested by straggling,

FIG. 1. Gravel slide formation invaded by scattered grasses, ***Arctostaphylos uva-ursi***, ***Quercus***, ***Pinus scopulorum***, ***P. flexilis*** and ***Pseudotsuga mucronata***.

scattered shrubs of the mountain mahogany, *Cercocarpus parvifolius* Nutt., the meadow sweet, *Holodiscus dumosa* (Nutt.) Heller, and oaks.

The well developed thicket stage is as frequently omitted or reduced as any one of the later stages. The thicket formation is at its best on the foothills and lower mountains where the forest stages are not common and in which there is often no clear evidence that it is being invaded by trees.

In these there may be equilibrium, hence they represent the final stage of a succession. However, near the mountains in a number of localities and on arid slopes the yellow pine finds protection for its seedlings and young trees in the oak thickets, and if undisturbed will readily establish the dry pine stage. At higher altitudes on the south and other arid slopes the oaks often form extensive, open thickets that are somewhat stable and these, when invaded by the pines, give way very slowly.

The dominant species of the south slope thicket enter the more arid grasslands slowly so that these slopes usually show an occasional small clump of oaks and widely separated individuals of the *Cercocarpus parvifolius* Nutt. The members of the grassland strongly resist further invasion by shrubs. Very often the grassland with its widely scattered shrubs is clearly and certainly being actively invaded by trees.

FIG. 2. A typical north slope spruce forest and the open yellow pine woodland on south slope.

Shrubs characteristic of the more arid situations are commonly absent from north slopes. Here is found a greater variety of species and these are less xerophytic in habit. The north slope thicket is more frequently suppressed than other thicket stages.

On south and other arid slopes the succession should terminate with the pine forest stage. Here a close formation is exceptional although small rather dense groves of yellow pines are not difficult to find. Often in these situations there is sharp alternation of grassland and woodland, which may be composed either of the open thicket or pine forest.

The ultimate stage on north slopes and other exposures where evaporation is not excessive, is the spruce forest. (See figure 2.) These forests vary much in closeness. As a rule they are open enough to permit the growth of one or two layers of woody plants below the canopy and an open, herbaceous floor cover. The shade is rarely dense enough to exclude shade loving plants.

THE HERBACEOUS GROUND COVER.

The clothing of gravel with vegetation is a very slow process. Observations, on certain slopes, extending over a period of from five to seven years have revealed little or no change. As previously stated lichens are not as a rule abundant. The first spermatophta to enter are herbaceous perennials of xerophytic habit and only the very hardiest species can gain a foothold on the young gravel slide. These plants have exceeding long tap-roots or an enormous area of fibrous roots which penetrate deeply, binding the gravel together. Attempts to dig holes of small diameter, one to two feet deep, in perfectly naked gravel are usually unsuccessful because of the falling in of the loose gravel; but they may be rather easily dug if several of the pioneer plants are near by. Many species of these first invaders form rosettes and only a few are freely branched. (See figure 3.) The following are some of the

species* that live in the gravel slide formation: tufted loco, *Aragallus multiceps* (Nutt.) Heller, small flowered gilia, *Gilia pinnatifida* Nutt., *Oreocarya virgata* (Porter) Greene, the evening primroses, *Pachylophus macroglottis* Rydb., and *P. montanus* (Nutt.) A. Nels., Colorado candy-tuft, *Thlaspi coloradense* Rydb., double bladder pod, *Physaria didymocarpa* Gray, whitlow-wort, *Paronychia pulvinata* Gray, *Pseudocymopterus anisatus* (Gray) C. & R., *Potentilla glandulosa* Lindl., *Potentilla effusa* Dougl., *Pentstemon glaber* Pursh, *Eriogonum flavum* Nutt., *Erigeron trifidus* Hook, *Mentzelia multiflora* (Nutt.) Gray, *Phacelia glandulosa* Nutt., *Scutellaria Brittonii* Porter and *Rubus strigosus* Michx. Sometimes the Indian hemp, *Apocynum androsaemifolium* L., and the fireweed, *Chamaenerion angustifolium* (L.,) Scop., are found.

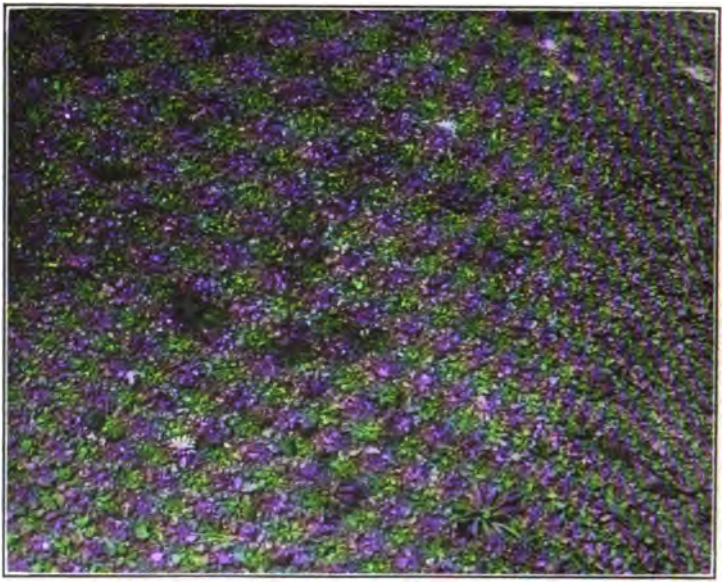

FIG. 3. Gravel slide formation showing rosettes of ***Gilia pinnatifida, Oreocarya virgata, Physaria didymocarpa*** and ***Thlaspi coloradense.***

* Professor Aven Nelson, of Wyoming University, has very kindly examined and identified a large number of my specimens.

Among the first grasses to invade the gravel are the oat grass, *Trisetum montanum* Vasey, and the wild rye, *Elymus condensatus* Presl. When grasses first appear they form widely separated bunches (see figure 4.) It is an easy task to find areas illustrating the gradual steps in the process of perfecting the grassland. The first condition is a very open one, the ground is slowly more completely covered. On the

FIG. 4. Invasion of the gravel slide formation by *Trisetum montanum.*

more arid slopes it is never entirely clothed (see figure 5.) These resemble, in a marked degree, the grass formation of the mesas and plains. They are invariably open, never supporting a sod, bunch grasses and other typical xerophytes dominating. The following list contains many of the species regularly found on the south slope grassland.

PRINCIPAL SPECIES: Blepharineuron tricholepis (Torr) Nash., Phleum pratense L., Hordeum jubatum L., Elymus condensatus Presl., E. ambiguus Vasey and Scribn., Trisetum

montanum Vasey, Agropyron tenerum Vasey, Poa compressa L., Bouteloua oligostachya (Nutt.,) Torr., Stipa viridula Trin., Koeteria cristata (L.) Pers., Festuca arizonica Vasey, Oreocarya virgata (Porter) Greene, O. glomerata (Nutt.) Greene, Lappula occidentalis (Wats.) Greene, Yucca glauca Nutt., Gilia aggregata (Pursh) Spreng., Pentstemon Torreyi Benth., Astragalus sparsiflorus Gray, Phacelia leucophylla Torr., Bahia dissecta (Gray) Brit., Aster Porteri Gray, Brickellia grandiflora minor Gray, Geranium Fremontii Torr., Aragallus Lambertii (Pursh) Greene, Helianthella Paryii Gray, Machaeranthera varians Greene, Artemisia frigida Willd.

SECONDARY SPECIES: Arenaria Fendleri Gray, Anogra coronopifolia (T. & G.) Brit., Euphorbia robusta (Engelm.) Small, Allium cernuum Roth., Campanula rotundifolia L., Eriogonum alatum Torr., Asclepias speciosa Torr., A. pumila (Gray) Vail, Castilleja integra Gray, Pentstemon humilis Nutt., P. unilateralis Rydb., Scutellaria Brittonii Porter,

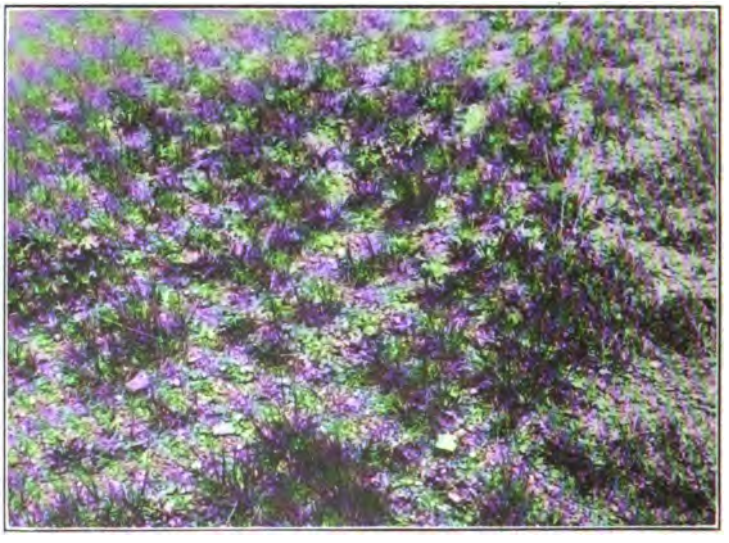

FIG. 5. The open ground cover of south slopes.

Erysimum asperum D. C., Echinocactus glaucus K. Sch., Physalis lanceolata Michx., Allionia diffusa Heller, Potentilla gracilis Dougl., P. glandulosa Lindl., P. pennsylvanica arachnoidea Lehm., Apocynum androsaemifolium L., Androsace diffusa Small., Phycelia neo-mexicana Thurber, Astragalus Shortianus Nutt., Erigeron flagellaris Gray, Chrysopsis foliosa Greene, Carduus Nelsonii Pammel., Antennaria aprica Greene, Liatris punctata Hook, Artemisia canadensis Michx., A. gnaphalodes Nutt., Senecio Nelsonii Rydb., S. spartioides T. & G. (Tall.), Solidago concinna A. Nels., Chrysothamnus frigidus Greene, Achillea millefolium L., Helianthus scaberrimus Ell., Erigeron glandulosus Porter.

On north slopes the conditions of life are more congenial. If trees and shrubs do not enter, these slopes often support so close a cover of grasses that at first glance it would be taken for a sod cover (see figure 6). Some of these north slope grasslands appear to have reached an equilibrium and are seemingly a final stage of a succession. In them no evidence of invasion by woody plants can be found, although seeds of both trees and shrubs may enter. It is possible that the grazing of livestock may account for the permanent north slope grassland.

PRINCIPAL SPECIES OF THE NORTH GRASSLAND: Muhlenbergia gracilis Trin., M. gracilis breviaristata Vasey, Agrostis hiemalis (Walt.) B. S. P., Poa interior Rydb., Danthonia intermedia Vasey, Stipa viridula Trin., Trisetum montanum Vasey, Festuca arizonica Vasey, Koeleria cristata (L.) Pers., Bouteloua oligostachya (Nutt.) Torr., Pulsatilla hirsutissima (Pursh) Brit., Anemone cylindrica Gray, Erigeron flagellaris Gray, E. subtrinervis Rydb., Gentiana affinis Greisb., Sedum stenopetalum Pursh, Saxifraga rhomboidea Greene, Pseudocymopterus sylvaticus A. Nels., Orthocarpus luteus Nutt., Thermopsis divaricarpa A. Nels., Arenaria Fendleri Gray, Synthris plantaginea Benth., Castilleja integra Gray, Potentilla gracilis Dougl., P. pennsylvanica arach-

noidea Lehm., Fragaria americana (Porter) Brit., F. pauciflora Rydb., Geranium Fremontii Torr., Achillea millefolium L., Senecio Nelsonii Rydb., Solidago missouriensis Nutt.

SECONDARY SPECIES: Calochortus Gunnisonii Wats., Thlaspi coloradense Rydb., Paronychia pulvinata Gray, Lychnis Drummondii Wats., Antennaria pulcherrima (Hook) Greene, Chrysothamnus pumilus Nutt., Senecio eremophilus Rich., Kuhnia Gooddingii A. Nels., Zygadenus elegans Pursh,

FIG. 6. A close grassland on a north exposure.

Blitum capitatum L. A large number of species of the south slope are also found in the north slope grassland.

The growth of herbaceous plants on the floor of the well developed thicket is scanty. In the dense oak thicket* the floor may be bare or covered with leaves, the accumulation of one or two years of the annual leaf fall. Even when light

* For lists of woody plants of the thickets and forests, see "The Distribution of Woody Plants in the Pike's Peak Region," Colorado College Publication, Science Series, Vol. XII, No. 6.

penetrates very few species are able to find sufficient water for normal development. Where the shrubs are somewhat separated the dominant herbaceous plants are the same as on the grassland.

The yellow pine woodlands are never so close that the floor is deprived of light, and yet the undergrowth of the well developed close pine grove is unusually scanty. A litter of needles and branches of considerable thickness often accumulates because of slow decay, and this no doubt destroys some herbaceous forms. As a rule the pine woodland is very open, the members of the grass and wood formations each holding their own in debatable territory, with the grasses occupying the greater area. Here and there may occur a shrub of *Cercocarpus parvifolius* Nutt., or more rarely *Ribes cereum* Dougl., or a small clump of oaks. In many of these mixed formations the open spaces are occupied almost equally by kinnikinic, *Arctostaphylos uva-ursi* (L.) Spreng., and the grasses.

When shrubs and trees enter the north slope grass formation they quickly alter the appearance of the living floor cover. Herbaceous plants and shrubs are thinned out as the shade of the canopy increases in denseness. Very few of these woodlands are close enough to destroy the entire living floor cover. However, even in the more open Douglas spruce forests the grasses are never so abundant as in the pine woodland. Occasionally in draws and toward the bottom of the slope of dense woods enough moisture is present to support a soft carpet of mosses and lichens. More frequently the floor has the appearance of the early grass stages, tufts of grasses and other herbaceous forms alternating with patches of naked gravel. As the forest increases in denseness the number of species, and of individuals of herbaceous plants, which are typical shade loving forms characteristic of these forests, decreases. In the open spaces occur many of the species characteristic of the north slope grassland.

Some of the principal species of herbaceous plants in the Douglas spruce forest: Aquilegia coerulea James, Thalictrum occidentale Gray, Delphinum romosum Rydb., Cyrtorhyncha ranunculina Nutt., Gentiana plebeja Cham., Heuchera parvifolia Nutt., Saxifraga austromontana Wiegand, Galium boreale L., Synthyris plantaginea Benth., Castilleja linariaefolia Benth., Smilacina stellata (L.) Desf., Corydalis aurea Willd., Draba streptocarpa Gray, Pyrola uliginosa Torr., Linnaea americana Forbes (woody trailing vine), Senecio cernuus Gray, Gymnolomia multiflora (Nutt.,) H. B. K., Solidago decumbens Greene, Oreochrysum Parryi (Gray) Rydb., Senecio eremophilis Rich., Potentilla glandulosa Lindl., Fragaria americana (Porter) Brit., F. pauciflora Rydb., Frasera speciosa Griseb., Androsacea diffusa Small, Lithospermum pilosum Nutt., Agrostis hiemalis (Walt.) B. S. P., Bromus Richardsonii Link., Koeleria cristata (L.) Pers., Bouteloua oligostachya (Nutt.) Torr., Trisetum montanum Vasey.

The number of species, and of individuals, is small in the gravel slide stage. They gradually increase in numbers and reach a maximum in the grassland formation and decrease materially in the woodland stages.

A striking feature of many long slopes is the progressive increase in the density of the plant cover from the crest of the ridge to the bottom of the slope. Barren gravel and typical first stages may occur near the ridge while below these is a very open grass stage, which lower down becomes decidedly close. On some of these slopes the typical forest formation may be found on the lower part.

A STUDY OF ENVIRONMENT.

Soil: The soil of the slopes considered is a coarse granite gravel, which extends often to great depths. It is a poor soil for holding moisture. Weathering has reduced the surface gravel to much finer grains, making it possible for some moisture to be conserved near the surface, but the ground

still remains very porous. Marked differences occur on the slopes examined. The naked gravel is constantly the coarsest, while the soil of the more stable and close grassland is composed of a high percentage of fine grains. A ground cover of dead leaves and other organic remains, or of grasses and other herbaceous plants, favors the accumulation of a fine grained black loamy soil overlying the gravel and mixing with it at the surface; these conditions obtain in the closed grasslands and in the woodlands where grasses, needles, mosses and lichens form a complete ground cover. The black loam extends down to varying depths difficult to measure because of its mingling with the gravel with no clear line of demarcation. In a few places the mixture was found to be eighteen or more inches deep; in others wholly absent. Whenever a break in the floor cover occurs the loam is washed away by the melting snow and the rain. The percentage of loam and fine grained gravel very frequently is greater toward the base of the slope. The usual variations in the constitution of the soil are shown in tables I and II.

These tables show the soil to be coarser at a depth of fifteen inches than at six inches. Also humus is largely confined to the uppermost layers of the soil and it, together with the finer grained soil, accumulates to a slight extent toward the bottom of the slope. The percentage of silt and humus is least in the open gravel and highest in the soil of the well developed north slope grass and woodland formations. Even when there is not a marked increase of humus the upper soil is finer because of the decomposition of the gravel by the roots of herbaceous plants.

TABLE I.

Number.	Formation.	Ground Cover.	Exposure.	Slope.	Soil at 6 Inches.*				Soil at 15 Inches.			
					Color.	Silt.	Sand.	Gravel	Color.	Silt.	Sand.	Gravel
						%				%		
1	Gravel slide	Scattered rosettes, etc.	NW.	24°	red	6.8	9.2	84	red	6.4	8.5	85.1
2	Gravel slide, 60 feet below No. 1	Scattered rosettes, few grasses	NW.	30°	red	10.4	14.6	75	red	4.6	10.6	84.8
3	Gravel slide	Few xerophytes	W.	27°	red	3.3	7.5	89.2	red	5.5	12.8	81.7
4	Gravel slide, 100 feet below No. 4	Few xerophytes	W.	27°	red	8.0	11.0	81	red	7.9	10.7	81.4
5	Grassland	Open, grasses and other herbs	N.	30°	black	17.9	16.7	65.4	red	4.5	8.9	86.6
6	Grassland	Closed, almost a sod	N.	14°	black	28.3	16.5	55.2	black	15.7	15.7	68.6
7	Grassland, 75 ft. bel. 6	Closed, almost a sod	N.	20°	black	47.5	22.3	30.2	black	18.8	19.7	61.5
8	Grassland	Open	S.	27°	red black	9.1	20.5	70.4	red	3.7	8.6	87.7
9	Oak thicket	Dead leaves, scattered grasses	S.	29°	black	12.9	10.9	76.2	black	10.8	14.5	74.7
10	Yellow pine woodland	Needles, scat'd grasses	S.	24°	black	13.4	19.7	66.9	black	9.5	14.1	76.4
11	Douglas spruce woodl'd	Moss, lichens, needles	N.	24°	black	15.4	12.9	71.7	red	8.4	9.3	82.3
12	Douglas spruce woodl'd 200 feet below 11	Moss, lichens, needles	N.	28°	black	16.1	10.3	73.7	red	7.9	5.3	86.8
13	Douglas spruce woodl'd	Open, grasses and other herbs	N.	22°	black	16.0	17.7	66.3	red	2.9	6.1	91.0
14	Douglas spruce woodl'd 150 feet below 13	Open, grasses and other herbs	N.	30°	black	21.0	18.5	60.5	red	7.8	14.4	77.8
15	Douglas spruce woodl'd (open)	Naked	N.	28°	red	4.2	7.4	88.4	red	3.6	8.4	88.0

*Soil structure was determined by the method recommended by Clement's in "Plant Physiology and Ecology," page 20. Two sieves of 1 mm. and .05 mm. mesh were used to separate the soil into gravel, sand and silt.

TABLE II. CRYSTOLA, OCTOBER 1, 1910.

FORMATION.	WATER-CONTENT. %		SOIL STRUCTURE AT 6 INCHES. %				SOIL STRUCTURE AT 15 INCHES. %			
	6 inches	15 inches	Humus*	Silt.	Sand.	Gravel.	Humus.	Silt.	Sand.	Gravel.
Gravel slide	2.5	2	0.2	8.2	7.5	84.1	0.3	6.3	6.9	86.4
South slope grassland	3.4	2.1	0.8	20.5	13.3	65.4	0.3	8.0	8.3	83.4
South slope yellow pine woodl'd	4.0	3.1	0.8	16.3	12.8	70.1	0.7	14.3	15.3	69.7
North slope grassland, top	7.6	4.1	1.9	41.2	15.5	41.4	1.0	20.1	11.3	67.6
North slope grassland, bottom	10.0	7.2	3.4	58.6	8.9	29.1	1.2	29.0	9.9	59.9
North slope spruce woodland, top	4.0	2.7	1.1	25.6	12.6	60.7	0.4	11.2	9.5	78.9
North slope spruce woodland, bottom	8.2	5.1	2.5	28.2	17.5	51.8	1.2	14.5	11.4	72.9

*Humus determinations were made by burning the fine grained portion passed through the .05 mm. sieve.

Soil Temperature: Soils with north exposures average cooler than those of south slopes. This difference is clearly seen on comparing the soils of the yellow pine woodland and the spruce forest. These woodlands are always cooler during the summer than the naked gravel and grass formations of similar exposure. Repeated observations, throughout a summer season, at a series of stations show that the soil temperature fluctuates less than the air, but that its variations correspond with and follow those of the air. During the month of August, 1909, Helen G. Strieby made daily readings morning, noon and evening on north and south slopes, at depths of six and eighteen inches, which show that there is less variation in soil at the depth of eighteen inches than at six inches; at the latter depth the effect of the day's sunlight and warmth is marked, especially on the south slope.

Soil Moisture: All determinations of water content were carefully made with soil, taken with a geotome at depths of six and fifteen inches, by drying it at 100° C. for about twenty-four hours. While often the surface of the soil is very dry, yet it is in the uppermost layers, in every formation studied, that the highest content of water occurs. Tables IV, V, VI, VII almost invariably show a higher percentage at six inches than at fifteen inches. As was expected the smallest amount was found to occur in the naked gravel and here, as in all other soils studied, the amount of water varies somewhat with the coarseness of the soil; the content falls as the amount of finer soil particles decreases. The irregularities in moisture content of all stages studied are, as a rule, to be explained by this variation in soil structure. With the entrance of grasses the soil becomes finer and more moisture is conserved. The determinations, on the whole, show an increase in moisture content in the successive stages of the succession, the highest percentage occurring in the woodland. On comparing similar formations on north and south slopes we find the higher percentage on the north slopes. Normally the moisture

content is greater near the base than near the top of the slope. All determinations made in this study have shown the soil of the oak thicket to be drier than that of similarly exposed grass and pine formations. Several series of observations, not recorded in the tables, show greater differences in the several formations. The table showing available and non-available water (table III) gives some striking differences.

It should be borne in mind that during the winter and spring more moisture is conserved on north exposures than on south slopes. Here the snow of the winter is protected from the sun's rays, hence it accumulates to some extent throughout the winter and remains often late into the spring.

Humidity: Clements* recommends simultaneous readings for habitat studies when different formations are to be compared. However, for the observations here recorded this was impossible, so they were made at each station at the time the soil samples were taken. In making the humidity readings the cog psychrometer was used. Even this unsatisfactory time arrangement revealed rather constant differences within the formations examined. They show only moderate differences, the gravel with the lowest, the grassland next, and the conifers woodlands the highest humidity. There is not a marked difference between north and south slopes. Readings made in as rapid succession as was possible for the observer to pass from station to station gave similar differences.

Available Moisture: The amount of available and non-available soil water content was determined for a number of typical plants of the several formations here considered. For these determinations soil containing the desired plant or plants was carefully cut out without disturbing the roots and transferred to the observers' camp where they were exposed to sunshine and wind but protected from rain. A soil sample was taken, at the time the larger block was cut, for the deter-

*Plant Physiology and Ecology.

mination of the total water content (holard). In each experiment the plants used for study were allowed to wilt and then another sample of soil was taken from the block and its moisture content determined. This residue or non-available water, Clements has called the echard. The difference between the holard and the echard is the chresard or the amount available to the plants under observation. Table III gives a statement of the more reliable data secured in this study. The percentages given are based upon the dry weight of the soil. Where careful inspection showed the roots to have been disturbed or injured the data has been rejected. It will be observed that plants of the gravel slide are the most xerophilous, the south slope grass formation forms are almost equally so, and grasses from among the yellow pines are not far different. The north slope grass formation forms are not as typically xerophytes, while the shade loving spruce forest species are distinctly mesophytic. It is evident from the table that though less moisture is usually available on the south slope, a greater part of it is there used by the plants than on the north slopes.

TABLE III.

FORMATION.	PLANTS.*	Holard †	Echard.	Chresard	SOIL STRUCTURE.		
					Silt.	Sand.	Gravel.
Gravel slide	Aragallus multiceps	4.4	1.5	2.9	10.4	10.0	79.6
Gravel slide	Potentilla glandulosa	6.4	2.5	3.9	7.7	12.7	79.6
South slope grassland	Artemisia frigida and grasses	10.0	2.3	7.7	24.1	19.8	56.1
South slope grassland	Astragalus sparsiflorus	3.9	2.6	1.3	18.5	14.8	66.7
Yellow pine forest	Grasses	7.4	3.0	4.4	20.8	12.3	66.9
North slope grassland	Gentiana affinis and grasses	12.6	6.0	6.6	44.8	12.7	42.5
Spruce forest	Thalictrum occidentale and grasses	24.1	11.3	12.8	37.4	22.2	40.4
Spruce forest	Heuchera parvifolia and Saxifraga austromontana	26.2	14.0	12.2	40.8	20.6	38.6

*All of these plants were dug on the same day.

†All figures here recorded are on the basis of 100 grams of the dry soil.

TABLE IV. ST. PETER'S DOME. Morning of August 2, 1910.

FORMATION.	FLOOR COVER.	Exposure.	Altitude. Feet.	Slope.	Sky.	Soil Temperature		Soil Water, Content. %		Soil Structure at 6 inches. %			Wind.	Humidity.
						12 in.	18 in.	6 in.	15 in.	Silt.	Sand.	Gravel		
Grassland	Very open	S.	8800	18°	clear	68.5	70.5	5.2	5.1	9.3	14.2	71.3	S.	35.5
Gravel slide	Few scattered plants	NW.	8770	14°	cl'dy	66.5	67.5	4.6	3.3	16.8	18.5	60.1	S.	36.0
Gravel slide	Few scattered plants	NW.	8690	27°	cl'dy	66.5	64.0	3.4	2.7	8.4	11.1	77.1	S.	35.5
Gravel slide	None	NW.	8500	27°	cl'dy	64.0	65.0	1.8	2.5	3.3	7.3	87.6	S.	42.0
Spruce woodland	Open, grasses, etc.	N.	8450	18°	cl'dy	60.0	62.0	6.8	6.9	10.7	19.3	63.2	S.	48.0
Spruce woodl'd, dense.	Open	N.	8390	22°	cl'dy	59.5	61.0	5.9	4.1	18.1	19.8	59.2	S.	55.0
Spruce woodl'd, dense.	Thick layer moss	N.	8300	27°	cl'dy	59.0	60.0	2.8	1.3	8.3	10.0	78.9	S.	46.5
Grassland	Open	N.	8000	22°	pt. cl.	71.0	69.5	4.6	5.3	4.8	8.7	82.1	S.	38.0
Grassland	Open	N.	7950	20°	pt. cl.	71.0	70.5	5.3	3.8	5.6	8.2	81.0	S.	41.0
Grassland	Open	S.	7950	23°	pt. cl.	72.0	70.5	5.3	5.0	7.3	12.0	75.3	S.	40.0
Grassland	Open	S.	8030	21°	pt. cl.	69.0	69.5	4.9	4.5	6.2	11.4	77.4	S.	39.0

TABLE V. CRYSTOLA. UPPER SERIES. Morning of August 10, 1910.

FORMATION.	FLOOR COVER.	Exposure.	Altitude. Feet.	Slope.	Sky.	Soil Temperature.			Soil Water Content. %		Soil Structure at 6 inches. %			Wind.	Humidity.
						Surface.	12 in.	18 in.	6 in.	15 in.	Silt.	Sand.	Gravel		
Gravel slide.....	Scat'd xerophytes..	NW.	8300	14°	clear	86.5	61.5	.....	4.3	5.1	6.0	9.7	80.0	W.	43.0
Gravel slide.....	Few grasses, etc...	NW.	8260	22°	clear	95.0	59.5	60.0	5.6	4.3	9.7	13.6	71.0	W.	45.5
Spruce woodland....	Open, shade plants	N.	8225	30°	clear	70.0	56.0	56.0	6.5	4.5	4.5	10.3	78.7	W.	47.0
Spruce woodland....	Needles, moss.....	N.	8100	30°	clear	92.0	54.0	55.0	7.4	2.7	4.3	5.9	87.1	W.	43.0
Grassland in large op'g in woodl'd...	Open.....	N.	8225	27°	clear	88.0	55.0	55.5	3.7	4.3	3.7	6.4	86.2	W.	47.0
Grassland.....	Grasses rather close	S.	8075	25°	clear	95.0	69.0	68.0	8.0	5.3	8.4	18.9	64.4	W.	46.0
Oak thicket.....	Dead leaves.....	S.	8140	22°	cl'dy	80.0	60.0	61.5	3.9	4.1	12.3	10.4	73.4	W.	48.0
Yellow pine woodl'd.	Needles, few grasses	S.	8200	22°	cl'dy	73.0	64.0	64.5	9.6	6.9	14.9	19.4	56.0	W.	50..

TABLE VI. CRYSTOLA. LOWER SERIES. Morning of August 11, 1910.

FORMATION.	FLOOR COVER.	Exposure.	Altitude. Feet.	Slope.	Sky.	Soil Temperature.			Soil Water Content. %		Soil Structure at 6 inches. %			Wind.	Humidity.
						Surface.	12 in.	18 in.	6 in.	15 in	Silt.	Sand.	Gravel		
Douglas spruce woodland	Open, scattered shade plants	N.	8350	22°	clear	76.0	57.0	58.0	7.0	3.2	15.7	17.5	59.8	E.	41.0
Douglas spruce woodland	Open, scattered shade plants	N.	8025	30°	clear	67.0	56.0	55.5	8.7	5.8	21.0	18.2	52.1	E.	47.5
Yellow pine woodl'd.	Needles, few grasses	S.	8025	24°	clear	71.0	57.0	57.0	5.5	5.5	20.5	11.3	62.7	E.	44.0
Grassland	Open	S.	8100	16°	cl'dy	90.0	65.0	66.0	5.0	5.0	18.0	13.6	63.4	E.	42.0
Grassland	Close	N.	8100	14°	cl'dy	90.0	64.0	65.0	7.0	2.0	24.5	13.6	54.9	E.	44.5
Grassland	Close	N.	8025	20°	cl'dy	91.0	62.5	64.0	12.1	6.4	51.4	8.5	28.0	E.	51.0

TABLE VII. CRYSTOLA. E. ROCK SERIES. Forenoon, August 17, 1910.

FORMATION.	FLOOR COVER.	Exposure.	Altitude. Feet.	Slope.	Sky.	Soil Temperature.			Soil Water Content. %		Soil Structure at 6 inches. %			Wind.	Humidity.
						Surface.	12 in.	18 in.	6 in.	15 in.	Silt.	Sand.	Gravel		
Gravel slide.....	Naked.....	NW.	8300	24°	cl'dy	64.0	60.5	61.5	4.0	3.9	6.3	8.5	80.8	S.E.	72.0
Grassland.....	Open.....	N.	8300	30°	clear	88.5	58.0	58.5	7.5	5.6	16.4	15.2	60.9	S.E.	67.0
Dougl. spruce w'dl'd	Moss and needles..	N.	8400	24°	cl'dy	58.0	54.0	54.5	6.0	4.2	14.4	12.1	67.5	S.E.	81.0
Dougl. spruce w'dl'd	Moss and needles..	N.	8200	28°	cl'dy	56.5	52.5	52.5	5.8	2.8	15.1	9.5	69.6	S.E.	77.0
Yellow pine w'dl'd..	Needles, few grasses etc.	S.	8200	23°	cl'dy	62.0	58.5	59.0	3.9	3.7	15.9	10.0	70.2	S.E.	74.0
Yellow pine w'dl'd..	Needles, few grasses	S.	8325	24°	cl'dy	61.0	58.0	58.5	2.7	3.2	5.8	6.6	84.9	S.E.	77.0
Oak thicket.....	Few grasses, etc...	S.	8400	29°	cl'dy	69.0	60.0	60.5	2.2	4.0	12.1	7.5	78.2	S.E.	61.0
Grassland.....	Open.....	S.	8400	27°	cl'dy	71.0	67.0	68.5	4.0	6.0	12.1	8.8	75.1	S.E.	73.0

THE HISTORY OF COLORADO MAMMALOGY.

By Edward R. Warren.

While the History of Colorado Mammalogy is neither a very long nor extensive one, it is a subject of sufficient interest to render it worth while to collect the data concerning it and bring it into form for convenient reference. It is only recently, within the last twenty years or so, that much has been done in the way of collecting and studying our smaller mammals; this statement applies not only to Colorado but to much of the rest of the country, for improved methods of trapping, collecting and preparing specimens have resulted in great strides within that period. It is to the activities of various departments of the Government of the United States that we owe a very large part of our knowledge concerning the mammals; in the case of Colorado this begins with the Pike Expedition, which was followed by Long's, Fremont's, the Pacific Railway Surveys, all under the War Department, and these were followed by the Wheeler and Hayden Surveys. Such work has been carried on in a much more modern fashion by the Bureau of the Biological Survey of the U. S. Department of Agriculture under the efficient direction of Dr. C. Hart Merriam, who has recently retired as Chief of the Biological Survey, and no doubt the work will be well carried on under the charge of his successor, Mr. H. W. Henshaw. Other institutions and private collectors have also done a considerable amount of work.

In the following pages I have mostly used the names in current usage except where it has been necessary to give those used by the author under consideration, and follow by an explanatory note as to the species probably meant. In some cases two or more forms may be covered by a single name and even when the locality is given it is not always

possible to determine the proper name with exactness. In the case of sundry references to *Eutamias quadrivittatus* which I found, the specimens might have been either that species or *E. operarius*, but as the former is first mentioned in this paper with its description by Say, it was not necessary to refer to it again, and *operarius* comes in as such with its description by Merriam.

I have also found it desirable at times to mention certain species more than once because of the fact that after their mention by the first author they have been described by a succeeding one as a new species or subspecies, thus making the second reference necessary. And similarly I have also found it necessary to make more than one reference to some species in order to definitely fix when they were first noted under the names by which they are known. The many changes in nomenclature and the vagueness of some of the names used by some of the earlier writers rendered such a course advisable.

1807:—PIKE. Pike's Journal is of course the first work in which we find the first references of any sort to Colorado mammals. He mentions Buffalo, Antelope, (under the name "Cabrie") Deer, presumably the Western White-tailed (*Odocoileus americanus macrourus*), as he mentions a deer of another species being killed when he attempted to ascend Pike's Peak, and this was the Mule Deer, *O. hemionus*. Pike also speaks of "Hare," and as he was along the Arkansas River, these would probably be Black-tailed Jack Rabbits, *Lepus californicus melanotis*, but he may also have seen the White-tailed Jack Rabbit, *L. campestris*, there, and one would think he must surely have run across that species in that part of the South Park reached by him, where it is the only species of Jack Rabbit.

1823:—SAY. The Long Expedition of 1819-20, the account of which was published in 1823, was accompanied by Thomas Say, the first trained naturalist to visit Colorado,

and more mammals were mentioned than by Pike, and not only that, but a number are described scientifically for the first time in the report. The mammals of the Long Expedition are as follows: Buffalo, *Bison bison,* Antelope, *Antilocapra americana,* White-tailed Deer, *O. a. macrourus,* Mule Deer, *O. hemionus,* Elk, *Cervus canadensis,* Beaver, *Castor canadensis frondator,* Prairie Dog, *Cynomys ludovicianus,* Rock Squirrel, *Citellus variegatus grammurus,* Say's Ground Squirrel, *Callospermophilus lateralis,* Colorado Chipmunk, *Eutamias quadrivittatus,* Grizzly Bear, *Ursus horribilis,* Swift Fox, *Vulpes velox,* the original description of which is in the book, but no definite type locality is designated, so that it cannot be said with any positiveness if the type locality is in Colorado or Nebraska, Wolves, *Canis nubilus,* Say's Bat, *Myotis subulatus,* and the Red Bat, *Nycteris borealis.*

1852:—BAIRD. From Say's report there is quite a space of time without any addition to the list of Colorado's mammals, until 1852 in fact, when Baird published in the Report of Stansbury's Expedition to Great Salt Lake the description of *Cratogeomys castanops,* taken at Bent's Fort, near the present site of Las Animas.

1853:—AUDUBON and BACHMAN. The following year, Audubon and Bachman, in the Quadrupeds of North America, described *Sciurus fremonti,* the type having been taken by Fremont.

During the fifties the various Pacific Railroad exploring expeditions were at work through the west, though they did but little in Colorado. I copy from Cooke's Birds of Colorado the following list of all the Government expeditions which entered Colorado previous to 1860. The interpolations in parentheses are mine.

1806-7. Lieut. Pike. Up the Arkansas River to Cañon City, across into South Park; then by a roundabout way into the San Luis Valley and New Mexico.

1820. Maj. Long. Up the South Platte to Denver; across the "Divide" to Colorado Springs, and south into New Mexico.

1844 and 1845. Capt. Fremont. Across the State via Grand River, Pueblo, Denver, and Fort Morgan.

1851. Capt. Pope. Came from New Mexico north and east to La Junta and east to Kansas.

1853. Capt. Gunnison. Crossed the plains to the Arkansas River, up that stream and its branches to Trinidad, Colorado, across southern Colorado to Fort Massachusetts (Fort Garland), over the Continental Divide (via Cochetopa Pass) to the Gunnison River, down this stream and the Grand River to Utah.

1855. Lieut. Warren. Just touched Colorado at Julesburg.

1856. Lieut. Bryan. Up the South Platte to Fort Morgan and north into Wyoming.

1859. Col. Loring and Capt. Macomb. Across the southwest corner of Colorado in passing from Utah into New Mexico.

The material gathered by these various expeditions was studied by Professor Baird and his assistants and the account of the mammals was published in Volume VIII of the Pacific Railroad Reports. Baird also published descriptions of certain forms prior to the above-named publication. The list of additions to the Colorado list proceeds as follows:

1855:—BAIRD. Proc. Acad. Nat. Sci. Phila., VII, pp. 334-5. In this paper are described from types taken within the limits of Colorado *Cynomys gunnisoni, Reithrodontomys montanus* and *Perodipus montanus.*

1857:—BAIRD. In volume VIII of the Pacific Railroad Reports, this being the work usually referred to as The Mammals of North America, Baird gives four more species in addition to those just named, as follows: *Lepus campestris,* a specimen of which is listed as being taken by Lieut. Bryan's

party on Cache la Poudre Creek, Nebraska; this is no doubt the Colorado stream of that name; *Perognathus flavus, Microtus modestus,* and a subspecies of *Citellus tridecemlineatus are* likewise named in this work from Colorado localities. In the case of the last-named species there is a little doubt as to whether one or two forms are included. He lists one specimen from Bent's Fort, this would be *pallidus;* there are two others collected by Kreutzfeldt, who was with the Gunnison party, and the locality of which is given as "Head of Arkansas;" if this were correct, they would also be *pallidus.* But the party did not, as I understand it, reach that region, and if the specimens came from the San Luis Valley, which the party crossed on the way to Cochetopa Pass, they would be *parvus,* and Baird would thus have added both forms of this spermophile to our fauna. Baird does not give the original numbers or dates of these specimens, so that the approximate locality cannot be ascertained.

1874:—ALLEN. In the Bulletin of the Essex Institute, Vol. 6, Nos. 3 and 4, March-April, 1874, appeared "Notes on the Mammals of Portions of Kansas, Colorado, Wyoming and Utah," by J. A. Allen. Part II of this paper, On the Mammals of Park County, Colorado, gives a list based on notes made in the summer of 1871, when Dr. Allen was in that region with the party from the Museum of Comparative Zoology, Cambridge. This is the first list of Colorado mammals I have found. I have stated elsewhere (in The Mammals of Colorado) that Coues' list of the mammals in the Maxwell Collection was the earliest, but Allen's, of which I did not know at the time antedates the other by several years. Much of Dr. Allen's information was obtained by conversation with hunters and others. 37 species are named in the paper, one of which, however, the Fisher, *Mustela pennanti,* has not been recorded by any other author, nor have I been able to find any evidence myself of its occurrence in Colorado. Of the 37 species, 25, if we include the Fisher, had not been previously reported

from the State. They are, aside from the species just named, *Ovis canadensis*, (previous to Allen I have come across two notices of the Mountain Sheep in Colorado, one of which is in Ruxton's "Adventures in Mexico and the Rocky Mountains," the first edition of which was published in 1848, though I have only seen the New York edition of 1855. Ruxton speaks of seeing them near the present site of Manitou. Mountain Sheep are also mentioned in Beckwith's Report of the Gunnison party as having been seen in the San Luis Valley, at the head or toward Saguache), *Lepus bairdi*, *Lepus callotis* = *melanotis* (this is not in the Colorado list, but in the Kansas list in the same paper Allen says he has "good authority for its occurrence in eastern Colorado and western Kansas"), *Lepus sylvaticus* var. *artemisia*, which would be the form now known as *pinetis*, *Ochotona princeps*, or *saxatilis*, as the specimens collected by the expedition were afterward named by Bangs, *Erethizon epixanthus*, *Thomomys rufescens*, (probably *T. fossor*), *Fiber zibethicus*, *Neotoma cinerea* (*orolestes*), *Hesperomys leucopus* var. *sonoriensis*, which is the form we now call *Peromyscus maniculatus rufinus*, *Marmota flaviventer*, *Putorius ermineus* = probably *P. arizonensis*, *Lutreola vison energumenos*, *Mustela martes* = *M. caurina origenes*, *Gulo luscus*, *Taxidea taxus*, *Mephitis mephitica* = either *hudsonica* or *varians* or very possibly both, *Ursus americanus*, named here as the Black Bear, *Vulpes macrourus*, *Canis nubilus*, *Canis latrans* (just what form of Coyote it is is not yet settled, but not *latrans*), *Lynx canadensis*, *Lynx rufus* (no doubt *uinta*), and *Felis hippolestes*.

1874:—TRIPPE. In Coues' Birds of the Northwest are given several pages of notes by T. Martin Trippe. On pp. 224–5 are mentioned several mammals as occurring in Colorado. Among these is the first record for the State of *Lutra canadensis*. Trippe also names *Aploceros montanus*, which is the name then in use for the Mountain Goat, but this is no doubt an error for *Ovis montanus* = *canadensis*, the Mountain Sheep.

1875:—COUES and YARROW. In 1875 was published the Report on the Zoology of the Surveys West of the 100th Meridian, commonly known as the Wheeler Surveys. The report on the mammals was by Drs. Coues and Yarrow. A few of the species mentioned from Colorado were additions to our fauna, though in one or two cases it is somewhat difficult to tell with certainty just what species was meant. Thus their *Lepus sylvaticus* from Fort Garland is probably what is now called *Sylvilagus auduboni warreni*, that being the Cottontail of that region. Their *Dipodomys phillipsi ordi* is no doubt *Perodipus montanus richardsoni* as the locality given is Twin Lakes. As in Baird's case they give records of *Citellus tridecemlineatus* from localities which would indicate both *pallidus* and *parvus*, these localities being South Park, Twin Lakes and Fort Garland. Their *Putorius longicauda* from Fort Garland may be *P. arizonensis*, which is certainly found in the San Luis Valley, but I have no records from that region for *longicauda*. They do, however, give two records which are positively new, *Procyon lotor* and *Antrozous pallidus*. They also mention *Aploceros montanus*, Rocky Mountain Goat, stating "one individual seen in Colorado by Lieutenant Marshall's party." A record never verified and no doubt erroneous.* At the end of their remarks on *Cervus canadensis* they say, "Remains of a Moose (*Alces americana*), said to have been killed in South Park, Colorado, in 1871, were observed by the expedition. The statement is open to doubt; if correct, it fixes the southernmost limit of the species." I have never been able to find anyone who knew anything about the matter. One would suppose that Allen, who was in that region in 1871, might have heard something of it, but he makes no mention of it in his paper, which is referred to above.

There is another possible record of the Moose in Colorado, and it may as well be mentioned here. Ernest Thompson Seton, in his recently published "Life Histories of Northern

*Possibly Marshall's party may have seen a domestic goat which had run wild, as it occasionally does.

Animals," quotes from a letter of H. W. Skinner of Chicago, dated March 4, 1901, as follows: "In the summer of 1887 I saw a small pair of well-bleached Moose antlers on the dirt roof of a log cabin near the foot of Sweetwater Lake, about 15 miles north of Dotsero, which is a station on the Denver & Rio Grande Railway, about 12 miles east of Glenwood Springs, Colo. The cabin was at least five or six years old, perhaps twice as old. It was at that time owned by a man named Peal, who told me that the Moose was the only one known to be in that country, and was killed while with a band of Elk or a bunch of stock, I have forgotten which." Mr. Seton places a ? before this quotation. I have no comments to make myself.

1877:—COUES. In his Fur Bearing Animals, Coues adds one or two species to our list, one being *Putorius nigripes.* He likewise gives *Spilogale putorius,* and made his description of the species from a specimen taken by C. E. Aiken near Fountain, El Paso County. This is the only species of *Spilogale* mentioned in the book. *Putorius* is an eastern species whose range is nowhere near Colorado, and the species to which Coues' specimen probably belonged is most likely *tenuis.* However, this is the first mention of a Spotted Skunk from Colorado.

1877:—COUES and ALLEN. In their Monographs of North American Rodentia, these authors give many Colorado localities in their lists of specimens of various species, but the present paper has to do only with those species which were new to the fauna of the State at the date of that publication, and there are but few of them, and with but one exception they are nearly unidentifiable. Thus *Thomomys talpoides umbrinus* is listed from southern Colorado, and the description of its color includes such a wide range of shades that it would cover practically every species of the genus now known to occur in the State. *Neotoma floridana* is given without definite locality, and might be *baileyi* or one of our other

Round-tailed Wood Rats. *Hesperomys leucopus sonoriensis* from Fort Lyons might be *tornillo* or *nebrascensis*. *Sciurus aberti ferreus* is the only species we can be sure of, specimens of which are recorded from near Colorado City and from the Divide.

1879:—COUES. In an appendix to "On the Plains and Among the Peaks, or How Mrs. Maxwell made her Natural History Collection," by Mary Dartt, published in 1879, is a list of the mammals in the collection with notes on other species, by Dr. Elliott Coues. There are 47 species named in this list, but few of which, however, are additions to the State list. Coues mentions *Lepus callotis texanus=californicus melanotis*, and, curiously enough, like Allen, he gives it only from report and not from his own knowledge. He mentions *Geomys bursarius*, no doubt *G. lutescens*, unless Coues was in error as to the genus, and that is hardly likely, and this is the first record of a *Geomys* from the State. He lists *Zapus hudsonius*, which may be either *Z. h. campestris* or *Z. princeps;* in either case it is the first Colorado record of *Zapus*. *Putorius vulgaris* is mentioned, and if it is the small weasel, is what we now call *P. streatori leptus*. *Urocyon cinereoargenteus scotti* is also new to the Colorado list.

1890:—MERRIAM. In North American Fauna No. 4, Dr. Merriam described *Evotomys galei* from a type specimen taken at Ward, Boulder County.

1891:—ALLEN. Dr. J. A. Allen described in Vol. III of the Bulletin of the American Museum of Natural History, *Peromyscus nasutus* from a type taken at Estes Park, Larimer County.

1893:—ALLEN. In Vol. V of the Bulletin of the American Museum of Natural History, Dr. Allen described *Thomomys fossor* and *Zapus princeps* from type specimens taken at Florida, La Plata County. *Mus musculus* is mentioned for the first time from Colorado, and *Sciurus aberti*, the specimens

proving to be subspecies *mimus*. *Eptesicus fuscus* and *Lasionycteris noctivagans* are also additions to Colorado's fauna.

1893:—THOMAS. In the Annals and Magazine of Natural History, 6th Ser., Vol. XI, Oldfield Thomas described *Perognathus fasciatus infraluteus* from a Loveland, Larimer County, type.

1893:—BAILEY. In the Prairie Ground Squirrels of the Mississippi Valley, Vernon Bailey makes the first mention of *Citellus obsoletus* and *C. elegans* as inhabitants of Colorado.

1894:—MERRIAM. In the Proceedings of the Biological Society of Washington, Vol. IX, Dr. Merriam described *Neotoma fallax* from a type taken at Gold Hill, Boulder County, and *N. orolestes* from a Saguache County specimen. In the case of the latter species it is the first mention under this new name, but it had been mentioned by Allen 20 years previously as *N. cinerea*, of which it is a subspecies.

1894:—ALLEN. In the Bulletin Amer. Mus. Nat. History, Vol. VI, Allen described (from a Kansas type) *Neotoma campestris*, now known as *Neotoma floridana baileyi* by reason of the priority of the latter name, and mentions a specimen from Fort Lyons.

1895:—MERRIAM. In North American Fauna No. 8, Merriam cites specimens of *Geomys lutescens* from Colorado, the first mention of this species, under this name at least.

1895:—TRUE. *Sciurus aberti concolor* was described by F. W. True in Vol. 17 Proceedings U. S. National Museum, from a type taken at Loveland. *Concolor* was changed in 1900 to *ferreus* because of being preoccupied, having been previously used for another species of *Sciurus*.

1895:—ALLEN. In Vol. VII, Bulletin Amer. Mus. Nat. History, Dr. Allen lists specimens of *Reithrodontomys dychei nebrascensis* from Cañon City and Loveland.

1895 (Dec. 31):—MERRIAM. In North American Fauna No. 10, Dr. Merriam described *Sorex tenellus nanus* from an *Estes Park type,* and also cites specimens of *Sorex obscurus* and *Neosorex navigator* from Colorado localities.

1896:—MERRIAM. In North American Fauna No. 11, Dr. Merriam mentions *Putorius cicognanii* from Silverton, (later he described the specimens as *P. s. leptus*), and figures a skull of *P. arizonensis* from Boulder County, this being the first Colorado record of that species under that name.

1897:—MERRIAM. In Proc. Biological Society of Washington, Vol. XI, Merriam described *Phenacomys preblei* from a Long's Peak specimen.

1897:—MILLER. In North American Fauna No. 13, G. S. Miller, Jr. adds several bats to the Colorado list, as follows: *Myotis lucifugus longicrus, Myotis californicus* (by implication), *Myotis evotis, Pipistrellus hesperus, Nycteris cinereus,* and *Corynorhinus macrotis pallescens.*

1897:—PALMER. In "The Jack Rabbits of the United States," *Lepus melanotis* is for the first time mentioned under that name as an inhabitant of Colorado.

1899:—BANGS. *Ochotona saxatilis* was described by Outram Bangs in the Proceedings of the New England Zoological Club, Vol. I, from the specimens taken in Park County in 1871 by Dr. Allen, and by him called *princeps.*

1899:—PREBLE. In North American Fauna No. 15, E. A. Preble described *Zapus hudsonius campestris,* and list specimens from Loveland.

1900:—BAILEY. Vernon Bailey in North American Fauna No. 17 adds *Microtus nanus, M. mordax* and *M. ochrogaster haydeni* to the Colorado list.

1900:—OSGOOD. In North American Fauna No. 18, Osgood notes specimens of *Perognathus flavescens* and *P. hispidus paradoxus* from various Colorado localities.

1901:—HOWELL. In North American Fauna No. 20, A. H. Howell mentions specimens from various Colorado localities of *Mephitis hudsonica* and *M. mesomelas varians*, being the first records under those names of the Skunks for the State.

1901:—MERRIAM. In his "Preliminary Revision of the Pumas," in Vol. 3 of the Proceedings of the Washington Academy of Sciences, Dr. Merriam makes the first Colorado references under that name of *Felis hippolestes*, previous authors always calling our cougar *concolor*. *Hippolestes* was described by Merriam in 1897 from a Wyoming type.

1902:—MERRIAM. *Lynx uinta* was described by Merriam in Vol. XV Proc. of the Biological Society of Washington from an Utah specimen, and Colorado included in its range. Most of the previous records for the State of *L. rufus* should undoubtedly have referred to *uinta*.

1902:—RHOADS. In the Proc. Acad. Nat. Sci. Phila., for 1902, S. N. Rhoads described *Mustela caurina origenes* from a specimen taken on Marvine Mountain, Rio Blanco County, this being the first mention of the Colorado Marten under this name, previous authors calling the animal *M. martes* or *M. americana*.

1902:—HOWELL. *Spilogale tenuis* described by Howell in Proc. Biological Society of Washington, Vol. XV, from a specimen taken at Arkins, Larimer County, and others mentioned from Estes Park.

1903:—MERRIAM. *Putorius streatori leptus* described in Proc. Biological Society of Washington, Vol. XVI, from a Silverton specimen, and prior records of the small weasel should be referred to this.

1905:—MERRIAM. *Eutamias amœnus operarius* described in Proc. Biological Society of Washington Vol. XVIII, from a type taken at Gold Hill, Boulder County.

1905:—ARNOLD. In Outdoor Life, November, 1905, Dr. W. W. Arnold makes the first mention of *Bassariscus astutus in* Colorado.

1906:—WARREN. In January, 1906, in Vol. XI of Colorado College Publications, the present writer published for first attempt at a complete list of Colorado mammals. In this a considerable number of species are recorded for the first time, and a number of others are first mentioned under current names. These species are as follows: *Eutamias hopiensis, Ammospermophilus leucurus cinnamomeus, Citellus variegatus utah, C. spilosoma major, Cynomys leucurus, Castor canadensis frondator* (first use of the subspecific name for the Colorado animal), *Mus norvegicus, Onychomys leucogaster pallescens, Peromyscus leucopus tornillo, P. nebrascensis, P. subarcticus=rufinus, P. luteus, P. auripectus, P. truei, Neotoma micropus, N. albigula (warreni), Thomomys clusius, T. aureus, Sylvilagus arizonæ=warreni, S. baileyi, S. pinetis* (prior authors had referred to all of these last three under various names), *Lynx baileyi, Canis nubilus* (first use of that name for the Colorado wolf), *Canis nebrascensis, C. lestes, C. mearnsi, C. estor* (the Colorado coyotes having heretofore been called *latrans*), *Putorius longicauda* (this being the first reliable record, the previous ones not being positively referable this species), *Sorex personatus* (*S. p. haydeni* was also recorded, but I think the specimens should be referred to *personatus*), *S. vagrans dobsoni,* and *Nyctinomus depressus. Energumenos* was also used for the first time for the Colorado mink.

1906:—HOWELL. In North American Fauna No. 26, this author records the capture of *Spilogale gracilis saxatilis* in southwestern Colorado.

1907:—CARY. In "Some Unrecorded Colorado Mammals," published in the Proc. Biological Society of Washington, Vol. XX, Merritt Cary adds 16 species to the Colorado list and confirms the occurrence of another. This paper was

especially timely because it straightened out much of the confusion as to the chipmunks of the State. The species added in this paper are: *Sciurus aberti mimus*, for the first time under the subspecific name, *Eutamias dorsalis utahensis*, *E. minimus*, *E. m. consobrinus*, *Citellus tridecemlineatus parvus*, *Onychomys brevicaudus*, *Neotoma desertorum*, *Reithrodontomys megalotis*, *Microtus pauperrimus*, *Thomomys clusius ocius*, *T. aureus pervagus*, *T. fulvus*, *Perodipus longipes*, *Perognathus apache* (*P. callistus* is also named tentatively for certain reasons, but no specimens have as yet been taken in the State), *Myotis californicus* confirmed by record of specimens taken, *Myotis c. ciliolabrum* and *M. yumanensis*.

1907:—NELSON. In the Proc. Biological Society of Washington, Vol. XX, E. W. Nelson described *Sylvilagus floridanus similis* from a Nebraska type, and records the capture of specimens in Colorado, and also described *S. audubboni warreni* from a type specimen taken at Coventry, Montrose County.

1907:—CARY. In a paper published in December, Proc. Biological Society of Washington, Vol. XX, Cary reports the taking of *Callospermophilus wortmani* in Routt County.

1908:—WARREN. Early in that year "Further Notes on the Mammals of Colorado" was published, and 9 new names added to the list. These were: *Peromyscus rufinus* (this is really not an addition, but the name replaces *subarcticus*, which does not apply to our species, and has no standing at all now for any species), *Peromyscus boylei rowleyi*, *Neotoma arizonae*, *N. cinnamomea*,* *Phenacomys orophilus*, *Lepus campestris townsendi*, *L. californicus texianus*, *Spilogale interrupta*, *Scalops aquaticus machrinus* and *Nyctinomus mexicanus*.

1908:—MERRIAM. In the Proc. Biological Society of Washington, Vol. XXI, Dr. Merriam described three sub-

*Goldman in his recent revision of *Neotoma* considers *cinnamomea* a synonym of *orolestes*, but I am inclined at present to disagree with him on this point.

species of mammals from Colorado types, one of which, *Neotoma albigula warreni* from Baca County, had been listed before as *N. albigula*; the others, *Eutamias minimus caryi* and *Thomomys talpoides agrestis*, were hitherto unmentioned and undescribed forms.

1908:—YOUNG. In the Proc. Academy of Natural Science, Philadelphia, Robert T. Young described *Eptesicus pallidus* from a specimen taken at Boulder.

1909:—WARREN. In the Proc. Biological Society of Washington, Vol. XXII, E. R. Warren described *Eutamias quadrivittatus animosus* from a Las Animas County specimen.

1909:—NELSON. In North American Fauna No. 29, Nelson records *Sylvilagus nuttalli grangeri* from northwestern Colorado.

1910:—WARREN. In "The Mammals of Colorado," published by Putnam, *Spilogale arizonæ* is added to the Colorado fauna, and *Canis frustror* included among our possible coyotes.

1910:—HOLLISTER. In the Proc. Biological Society of Washington, Vol. XXIII, N. Hollister describes *Fiber zibethicus cinnamominus* from a Kansas type, and includes eastern Colorado in its range. In a personal letter Mr. Hollister writes that he had typical examples from Wray, Yuma County, and intermediate from Ward, Boulder County, these latter being nearest *cinnamominus*.

1910:—GOLDMAN. In North American Fauna No. 31, "Revision of the Wood Rats of the Genus *Neotoma*," E. A. Goldman adds *Neotoma micropus canescens* and *N. cinerea rupicola* to the Colorado fauna, the former from 18 miles south of La Junta, and the latter from Avalo and Pawnee Buttes, Weld County.

SPECIES OF MAMMALS DESCRIBED FROM COLORADO TYPE LOCALITIES.

An interesting side of this subject is the number of species and subspecies of our mammals whose type localities are in Colorado. These number no less than thirty, about a fifth of the total number of mammals now credited to our State. Of these, ten were described before 1860, and, as a matter of fact, not a single new species of mammal was described from a Colorado type from 1857 until 1890, and curiously enough, since then the additions average one a year. Certainly this large proportion of new species is a good testimonial as to the variety and richness of our fauna.

The list of these species with their type localities, is as follows:

1823:—SAY. *Eutamias quadrivittatus*, from along the Arkansas River, about 26 miles below Cañon City; *Callospermophilus lateralis*, from the same place; *Citellus variegatus grammurus*, from the Purgatoire River, Lat. 37° 32′ N., Lon. 103° 31′ W.; and *Myotis subulatus* from about the present site of La Junta.

1852:—BAIRD. *Cratogeomys castanops*, from Bent's Fort, about where Las Animas is now.

1853:—AUDUBON and BACHMAN. *Sciurus fremonti*, the exact type locality of which is in doubt, but which is apparently somewhere in the South Park.

1855:—BAIRD. *Cynomys gunisoni*, from Cochetopa Pass; *Reithrodontomys montanus* from somewhere on the east side of the San Luis Valley between Fort Garland and Crestone; *Perodipus montanus*, from Fort Massachusetts, where Fort Garland is now. These were all taken by the party under Captains Gunnison and Beckwith.

1857:—BAIRD. *Microtus modestus*, from Cochetopa Pass, also taken by the above-mentioned party.

1890:—MERRIAM. *Evotomys gapperi galei*, from Ward, Boulder County.

1891:—ALLEN. *Peromyscus nasutus*, from Estes Park, Larimer County.

1893:—ALLEN. *Zapus princeps* and *Thomomys fossor*, from Florida, La Plata County.

1893:—THOMAS. *Perognathus fasciatus infraluteus*, from Loveland, Larimer County.

1894:—MERRIAM. *Neotoma fallax*, from Gold Hill, Boulder County, and *Neotoma cinerea orolestes*, from 20 miles west of Saguache, in the county of that name.

1895:—TRUE. *Sciurus aberti concolor*, from Loveland; in 1900 True changed the name to *ferreus* because of *concolor* being preoccupied.

1895:—MERRIAM. *Sorex tenellus nanus*, from Estes Park.

1897:—MERRIAM. *Phenacomys preblei*, from Long's Peak, Larimer County.

1899:—BANGS. *Ochotona saxatilis*, from Montgomery, Park County.

1902:—RHOADS. *Mustela caurinà origenes*, from Marvine Mountain, Rio Blanco County.

1902:—HOWELL. *Spilogale tenuis*, from Arkins, Larimer County.

1903:—MERRIAM. *Putorius streatori leptus*, from Silverton.

1905:—MERRIAM. *Eutamias amœnus operarius*, from Gold Hill, Boulder County.

1907:—NELSON. *Sylvilagus auduboni warreni*, from Coventry, Montrose County.

1908:—MERRIAM. *Neotoma albigula warreni*, from Gaume's Ranch, Baca County; *Eutamias minimus caryi* and *Thomomys talpoides agrestis* from Medano Ranch, Costilla County.

1908:—YOUNG. *Eptesicus pallidus*, from Boulder.

1909:—WARREN. *Eutamias quadrivittatus animosus*, from Irwin's Ranch, northeastern Las Animas County.

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The Parasite Fauna of Colorado

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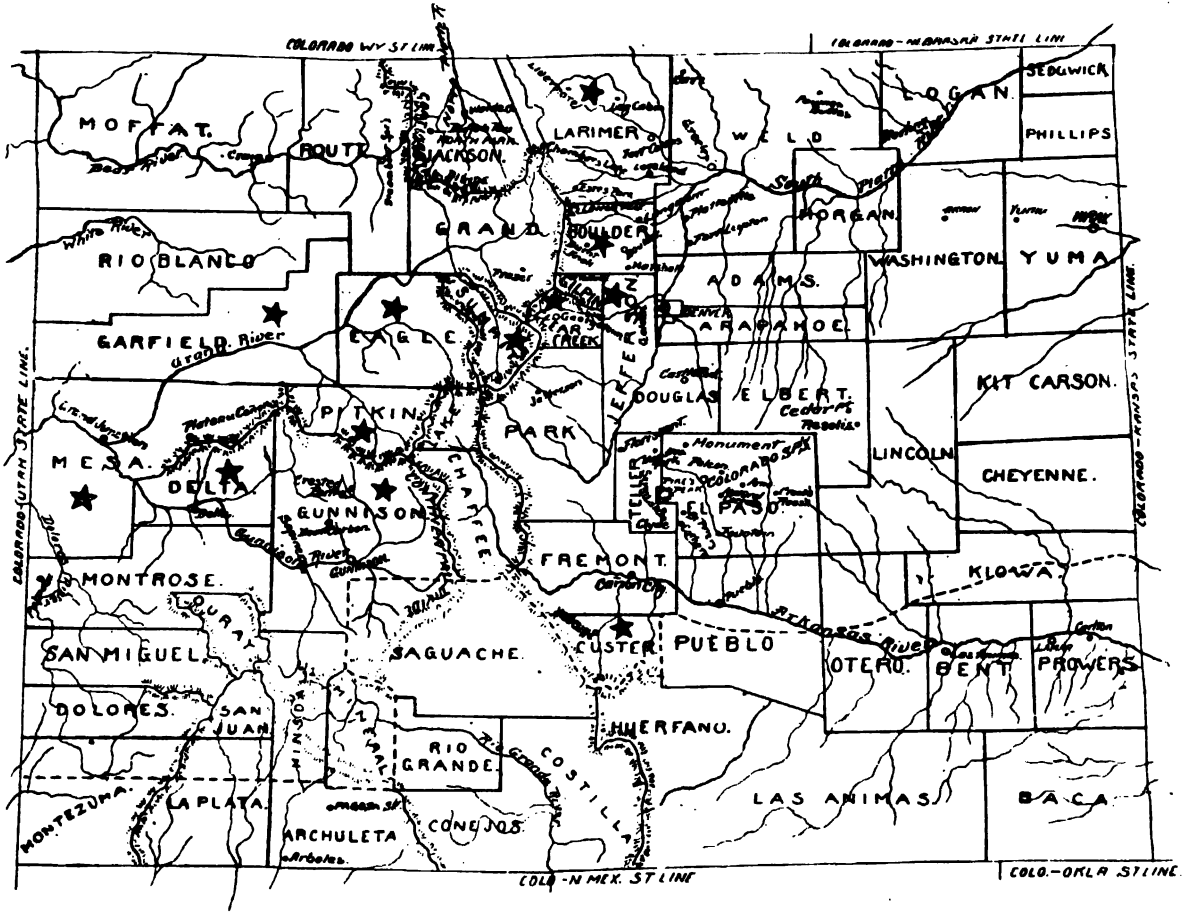

Map of Colorado Showing Places and Areas from which Parasites are Recorded.
☆ Counties from which some Parasites are recorded with no location specified.
------ Line marking Northern boundary of area quarantined for sheep scab.

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THE PARASITE FAUNA OF COLORADO.

By MAURICE C. HALL,
Assistant Zoologist, U. S. Bureau of Animal Industry.

I. INTRODUCTORY.

The publication of a partial list of the fauna of Colorado, as part of an organized biological survey of the state, by Ramaley, Cockerell and Henderson, has led the writer to compile the list of parasites given in this paper. This compilation was the more feasible in that the writer was engaged in government parasitic investigations in this state, and was the more willingly undertaken in that it is the writer's belief that a survey of the parasite fauna has as much value, although its data are modified by the dominant condition of parasitism, as a survey of free-living groups. The ways in which such a survey of parasite fauna may be of value have been discussed in a previous article by the writer. (See Hall, 1912). No list of the parasites of this state or any other state has ever been published, so far as the writer is aware. This list is to be looked upon as a preliminary record which will facilitate the making of additional records by serving as a nucleus about which such records may be grouped. In addition to unpublished records, it aims to summarize the scattered references already published and thereby simplify the work of future investigators.

Parasitism is a condition found in many groups of animals and records from all these groups have been admitted to this list with the exception of the insects parasitic on insects. This includes the large and important groups of the Icheumonidæ, Tachinidæ, etc., which do not properly come within the scope of the writer's work. Even as it is, the record covers so many groups, some of which are commonly studied from a standpoint quite different from that of an interest in parasitism itself, that

the list could not have been nearly so complete had it not been for the assistance and cooperation of a number of other workers who have kindly furnished me with data. Records not heretofore published have been supplied by Professor Cockerell and Dr. Ellis of the University of Colorado, Professor Gillette and Dr. Kaupp of the Colorado State Agricultural College, Mr. Frederick Knab of the U. S. Bureau of Entomology, Dr. Garrison of the U. S. Naval Medical School, Professor Young of the University of North Dakota, and Professor Ward of the University of Illinois. Mr. Warren of Colorado College has turned over to the writer for examination a number of parasites and a large amount of alcoholic host material from which the writer has collected numerous interesting parasites. The writer is indebted to Mr. R. S. Clifton for access to the records of the U. S. Bureau of Entomology. Host animals have been identified by Mr. Warren (mammals), Mr. Schwarz (coleoptera), and Mr. Caudell (orthoptera). Incidental identifications and collections are credited in the text. The larger number of records are from the collection of the U. S. Department of Agriculture, the U. S. National Museum and the U. S. Public Health and Marine Hospital Service. Finally, this work would have been quite impossible had it not been for the courtesy of President Slocum and Profesor Schneider of Colorado College who have very kindly permitted the writer to use the laboratories and equipment at Colorado College during the course of these collections and some government investigations.

Generally speaking, the climate of Colorado is too dry to favor the multiplication and spread of parasites. The high altitude over much of the state results in a relatively low temperature, especially at night, and this also is unfavorable to the life cycle of most parasites. Parasites thrive best in warm, moist localities, the tropics being the place where they occur most abundantly, and Colorado for the most part is cool and dry. However, the very fact that natural conditions in Colorado are so little suited to parasite life lends additional interest to the study of such parasites as persist in spite of conditions naturally un-

favorable to parasites in general. Such as do persist are presumably adapted to the temperature and moisture conditions prevalent over Colorado or else find local conditions which permit of parasite development. Thus a leaky watering trough might furnish the stomach worm of sheep with the necessary moisture which the rain and dew at the same point would not furnish.

Some of the forms given in the following list are apparently new and so are listed under a generic name only or even in some general way without a generic name. Two abbreviations are used throughout: coll.—collector or collected by; det.—determined by. In some cases, the writer has taken the liberty of substituting synonymous scientific names for the ones furnished him by various persons who have sent records with their own identifications. This is partly in the interests of uniformity to make them agree with the writer's records and partly to make them conform to the latest scientific acceptation.

II. PARASITE RECORDS.

(I). PROTOZOA.

1. *MASTIGOPHORA.*

CRITHIDIA MELOPHAGI:—*Melophagus ovinus;* intestine. Coll. and det. Hall, 1911, Colorado Springs. Apparently common.

TREPONEMA PALLIDA:—*Homo sapiens;* any tissue. As might be expected, a survey of Colorado medical literature shows the disease due to this organism, syphilis, to be fairly common, but there appear to be no data showing how the frequency of the disease in Colorado compares with that in other places.

2. *SPOROZOA.*

AMOEBA MELEAGRIDIS. See *Coccidium tenellum.*

COCCIDIUM OVIFORME:—*Bos taurus;* liver. Det. Kaupp, 1908-'11, Fort Collins abattoir. 4 cases. *Coccidium oviforme* is a synonym of *Eimeria stiedae.* In this host the parasite would be more apt to be a variety of *Coccidium perforans.*

COCCIDIUM PERFORANS. See *Coccidium oviforme.*

COCCIDIUM TENELLUM:—*Gallus gallus, Meleagris gallopavo;* ceca and liver. Coll. and det. Kaupp, 1908-'11, Fort Collins. 2 cases in chicken; 18 cases in turkey. Also reports by Kaupp (1911). This is the organism credited by some writers with causing "white diarrhea" in chickens and "blackhead" in turkeys; often called *Amoeba meleagridis.* The correct name is a matter of dispute.

EIMERIA STIEDAE. See *Coccidium oviforme.*

Gregarines:—*Platystethus americanus;* intestine. Coll. Hall, 1911, Colorado Springs. Common.

Gregarines:—Mountain cricket; intestine. Coll. Hall, 1906, St. Peters. Reported in Hall (1907).

HAEMOGREGARINA SP:—*Thamnophis sp.;* blood. Coll. and det. Hall, 1907, Colorado Springs. 1 case.

HIRMOCYSTIS RIGIDA:—*Melanoplus coloradensis, Melanoplus sp.;* intestine and occasionally body cavity. Coll. and det. Hall, 1906, Canon City (reported by Hall, 1907); Hall, 1911, Colorado Springs (common); Ellis, 1911, Boulder (33 per cent infected of 200 host insects examined). *Gregarina melanopli* Crawley, 1907, is a synonym of *H. rigida,* Hall, 1907, Crawley's name being published a little later. Crawley and the writer are agreed that the species are identical. The correct generic name is a matter of uncertainty and must remain so until the cyst development and spore formation are better known. Crawley reported this form from Pennsylvania and the writer has reported it from Nebraska and has since found it in 1907 at Bethesda, Maryland.

MONOCYSTIS SP.:—Earthworm; (seminal vesicles and body cavity, presumably). Coll. Ramaley and Watkins, Boulder. Reported by Cockerell (1911).

PLASMODIUM SP.:—*Homo sapiens;* blood. Coll. Drs. Moleen, Lyman, Monghan, Roe and Matthews, Denver (?); det. Matthews. 5 cases. Reported by Matthews (1909). Patients had been in other states from 2 to 10 years previous. Matthews concludes that malaria is not rare in Colorado in patients coming from malarial areas outside of the state. In this connection, Professor Gillette furnishes an important record in a letter to the writer in which he notes that Professor Weldon has found an *Anopheles* in Delta County and says, "I believe this is the first record of the occurrence of this genus in Colorado and is liable to be accountable for an outbreak of malaria on the western slope".

SARCOCYSTIS MIESCHERI:—*Bos taurus;* heart. Det. Kaupp, 1908-'11, Fort Collins abattoir. 1 case.

SARCOCYSTIS TENELLA:—*Ovis aries;* oesophageal muscles. Coll. Ransom and Hall, 1911, Resolis and Amo; Hall 1911, Colorado Springs abattoir in sheep from Amo; det. Ransom. Common.

STYLOCEPHALUS GIGANTEUS:—*Eleodes hispilabrius, Eleodes*

spp.; intestine. Coll. and det. Ellis, 1911, Boulder. Described as a new species by Ellis (1912). Coll. Ransom, 1911, Amo (in *E. hispilabris*), det. Hall. Common.

3. *RHIZOPODA.*

CYTORYCTES VARIOLAE:—*Homo sapiens;* in pustules. The presence of this supposed parasite, which is held by some to be the cause of measles, is assumed from the reports of measles in the reports of the Colorado State Board of Health. Cockerell (1911) reports it from Boulder on a similar basis. For 1910, Trask (1911) reports from Colorado 1,096 cases, a case rate of 136.23 per 100,000 inhabitants. Some protozoologists hold that no true parasitic organism has yet been found in measles.

NEURORYCTES HYDROPHOBIAE:—*Homo sapiens, Canis familiaris, Bos taurus, Equus caballus,* (?) *Felis domestica,* (?) *Canis occidentalis;* nervous system. Coll. and det. Glover and Kaupp, 1908-'10, Greeley (in horse, cow and dog), Loveland, Longmont (dog), Fort Collins (dog), Fort Lupton, Platteville, Castle Rock, Denver (dog, cow, (?) cat, (?) wolf). Reported by Glover and Kaupp (1910). Its presence in man is assumed from the reports of cases of rabies, of which this is believed by some to be the cause, in the reports of the Colorado State Board of Health. As in the preceding case, some protozoologists hold that the so-called *Neuroryctes hydrophobiae* is not a parasitic organism.

4. *INFUSORIA.*

NYCTOTHERUS SP.:—Frog; (intestinal tract, presumably). Coll. Ramaley, Boulder County. Reported by Cockerell (1911).

OPALINA SP.:—Frog; (intestinal tract, presumably). Coll Ramaley, Boulder County. Reported by Cockerell (1911).

(II.) PLATYHELMINTHA.

1. *TREMATODA.*

FASCIOLA AMERICANA. See *Fasciola magna.*

FASCIOLA CARNOSA. See *Fasciola magna.*

FASCIOLA HEPATICA:—*Bos taurus*; liver. Coll. and det. Dr. Ayres, 1907-'09, Fort Collins abattoir in cow probably shipped in from out of state. (Statement made in personal conversation.) May have been *F. magna*, q. v.

FASCIOLA MAGNA:—*Bos taurus*; liver. Coll. Francis, Colorado Springs; det. Hassall as a new species and published by Hassall (1891a) as *Fasciola carnosa*. This name was preoccupied and later Hassall (1891b) changed it to *Fasciola americana*. The correct name is *Fasciola magna* (Bassi, 1875) Stiles, 1894. The specimens from which Hassall described the species were collected in abattoir inspection, and the cattle from which they were collected were probably from New Mexico or from some state along the Gulf of Mexico where the parasite is enzootic. There are several reasons for thinking that this parasite has no foothold in Colorado. The prevailing dryness over most of the cattle ranges in this state results in a scarcity of such intermediate hosts as snails, which are essential in the life cycle of flukes of this genus, so far as these life histories are known.

Trematode:—Frog; lung. Coll. Hall, 1906, Canon City. Common.

Trematode:—Trout; stomach and intestine. Fraser River, Fraser. In Dr. Ward's collection.

2. *CESTODA.*

ANOPLOCEPHALA SP.:—*Evotomys gapperi galei, Microtus pennsylvanicus modestus*; intestine. Coll. Young, 1908, Longs Peak, det. Young and Hall.

ANOPLOCEPHALA SP.:—*Peromyscus sp.*, intestine. Coll. Young, 1908, Longs Peak, det. Young and Hall.

APLOPARAKSIS (?):—*Sternella magna neglecta;* intestine. Coll.?, 1894, locality?; det. Ransom. In Colorado College Collection.

BOTHRIOCEPHALUS LATUS. See *Dibothriocephalus latus.*

Cestode:—*Callospermophilus lateralis;* intestine. Coll. Hall, 1911, Clyde. 1 specimen.

Cestode:—*Centrocercus urophasianus;* intestine. Coll. C. H. Merriam, 1892. In Bureau of Animal Industry Coll. This is *Rhabdometra nullicollis,* according to Dr. Ransom, and may be part of the same material as the National Museum specimens from which Dr. Ransom described *Rh. nullicollis,* q. v.

Cestode:—*Citellus tridecemlineatus pallidus;* intestine. Coll Hall, 1911, Amo; Hall, 1911, from alcoholic host material collected by Warren, 1910, Colorado Springs. 3 cases.

Cestode:—*Cyanocitta stelleri diademata;* intestine. Coll. Hall, 1911, from alcoholic host material collected by Warren, 1909, Bear Creek Canon, near Colorado Springs. 1 case.

Cestode:—*Homo sapiens;* intestine. Coll. C. F. Schollenberger, 1903, Denver. Reported by Schollenberger (1903). Tapeworm 39 feet long. Probably *Taenia saginata,* q. v.

Cestode:—*Neotoma floridana baileyi;* intestine. Coll. Hall, 1911, from alcoholic host material collected by Warren, 1911, Cedar Point, Elbert County. 1 specimen.

Cestode:—Myrtle warbler; neck. (Probably as a result of intestines, the actual site of infection, being torn by shot.) Coll. S. A. Johnson, 1903, Fort Collins.

Cestode:—Rabbit; intestine. "D. K." (See Stewart, 1900.), writing from some unspecified place in this state, says that almost every rabbit at that place had tapeworms. It is imposible to say what tapeworm this was, but see *Davainea salmoni.*

Cestode:—Red-headed woodpecker; intestine. Coll. Hall, 1906, Cather's Springs. 1 case.

Cestode:—*Thomomys fossor;* intestine. Coll. Hall, 1911, from alcoholic host material collected by Warren, 1909, Ruxton Creek, near Colorado Springs. 1 case.

Cestode:—*Thomomys sp.;* intestine. Coll. Young, 1908, Longs Peak.

Cestode:—Trout. Fraser River, Fraser. In Dr. Ward's collection.

Cestode:—*Zenaidura macrura carolinensis;* intestine. Coll. Hall, 1911, Amo.

CHOANOTAENIA INFUNDIBULUM:—*Gallus gallus;* intestine. Coll. and det. Hall, 1911, Colorado Springs (1 case); Kaupp, 1908-'11, Fort Collins (2 cases found in 87 post-mortems).

CITTOTAENIA MOSAICA:—*Sylvilagus nuttalli pinetis;* intestine. Coll. Hall, 1906, near Seven Lakes. Described as a new species by Hall (1908). A tapeworm found in the same host near Gunnison by Mr. Gleason Lake of Colorado Springs and verbally described to the writer is probably the same species.

COENURUS CEREBRALIS. See *Multiceps multiceps.*

COENURUS SERIALIS. See *Multiceps serialis.*

CYSTICERCUS BOVIS. See *Taenia saginata.*

CYSTICERCUS CELLULOSAE. See *Taenia solium.*

CYSTICERCUS PISIFORMIS. See *Taenia pisiformis.*

CYSTICERCUS TENUICOLLIS. See *Taenia hydatigena.*

DAVAINEA SALMONI:—*Lepus campestris, Sylvilagus auduboni baileyi;* intestine. Coll. S. A. Johnson, 1903, Fort Collins (in *L. campestris*), det. Ransom; coll. and det. Hall, 1911, Resolis (in *L. campestris* and *S. a. baileyi*), Amo and Crow's Roost (in *S. a. baileyi*). The great majority of the cottontail rabbits examined at these points in Elbert and El Paso Counties harbored these worms.

DAVAINEA TETRAGONA:—*Gallus gallus;* intestine. Coll. Hall, 1911, Amo; det. Hall and Ransom. 1 case.

DIBOTHRIOCEPHALUS LATUS:—*Homo sapiens;* intestine. Coll. at Leadville in immigrant. Reported by Dock (1898). Coll. In U. S. Hygienic Laboratory Collection. Reported by Pfender (1910). Dr. Hall of Denver, according to a secretary's abstract (see Hall, 1905), stated before the Denver Clinical and Pathological Society that a worm previously exhibited by him was a specimen of *Bothriocephalus latus.* This was perhaps the specimen collected by Dr. Walker. The correct name of this worm is *Dibothriocephalus latus.*

There are no further data given by the secretary and it can only be assumed that the specimen was collected in Colorado. In any case, the parasite must have been imported. Dr. Walker's specimen was collected from a Swede. An endemic center of infection has recently been discovered in the United States in northern Michigan.

DIPYLIDIUM CANINUM:—*Canis familiaris, Felis domestica;* intestine. Coll. and det. Kaupp, 1908-'11, Fort Collins (from dog); coll. Ellis, 1911, Boulder (from cat), det. Hall.

ECHINOCOCCUS GRANULOSUS:—*Bos taurus;* liver: (?) *Homo sapiens.* Det. Kaupp, 1908-'11, Fort Collins abattoir. 2 cases from cow. Dr. Hillkowitz, according to a secretary's abstract in *Colorado Medicine* for Sept. 20, 1904, read a paper entitled "Case of Echinococcus". There are no further data to indicate whether the case occurred in Colorado and in man.

HYMENOLEPIS SP.:—*Cynomys ludovicianus;* intestine. Coll. Hall, 1911, Resolis; det. Ransom. 1 specimen from 3 host animals at Resolis; none in 2 host animals from Natural Corral, El Paso County.

ICTHYOTAENIA LÖNNBERGI (?). See *Proteocephalus lönnbergi* (?).

LIGULA SIMPLICISSIMA:—Sucker. Coll. S. A. Johnson, 1903, Fort Collins, det. Ransom.

METROLIASTHES LUCIDA:—*Meleagris gallopavo;* feces (the intestine is the site of infection). Coll. and det. Hall, 1911, Colorado Springs. The turkeys were said to have come from Texas.

MONIEZIA EXPANSA:—*Ovis aries;* intestine. Curtice (1889) says that Faville in 1884, in an article not available to me, reported this worm under the name of *Taenia expansa* from Fort Collins. Faville said that the worms occurred in the intestine and gall ducts and were 6 inches to 6 feet long. The worms in the gall ducts were undoubtedly *Thysanosoma actinioides.* The intestinal worms 6 feet long were certainly *Moniezia* and might or might not have been *M.*

expansa. Curtice (1890) records an outbreak of disease due to *M. expansa* occurring annually in a Colorado flock during July and August. Stiles and Hassall (1893) record this parasite from Colorado on the authority of Curtice.

MONIEZIA TRIGONOPHORA:—*Ovis aries;* intestine. Coll. and det. Hall, 1911, Amo. 2 cases.

MULTICEPS MULTICEPS:—*Ovis aries;* brain. Hall (1910) notes 2 records reported by the veterinary editor of the *American Sheep Breeder* in 1901 and 1905, and states in comment that these cases are doubtful. This parasite, usually called *Coenurus cerebralis,* causes a disease known as gid. This disease has no foothold in Colorado and any cases occurring in this state would probably be imported from northern Montana where the disease is enzootic. Curtice (1982) records the adult tapeworm, known as *Taenia coenurus,* from the intestine of a dog in Colorado, noting that it might be another species. Hall (1910) on re-examination of material finds that it is not *Multiceps multiceps.*

MULTICEPS SERIALIS:—*Lepus sp., Sylvilagus sp.;* connective tissue. Coll. 1911, Carlton; det. Hall. This parasite is recorded by Hall (1910) as seen by Dr. Shantz in jackrabbits at Wray and as seen by Curtice in Colorado as early as 1887 and 1888. Mr. Horace Ragle of Colorado Springs tells me that he found it in a cottontail at Colorado Springs in 1910.

PROTEOCEPHALUS LÖNNBERGI (?):—*Amblystoma tigrinum.* Coll. S. A. Johnson, 1903, Fort Collins, det. Ransom. In U. S. National Museum catalogue as *Ichtyotaenia lönnbergi* (?).

RHABDOMETRA NULLICOLLIS:—*Centrocercus urophasianus;* intestine. (Coll. in 1892). Described as a new species by Ransom (1909).

TAENIA COENURUS. See *Multiceps multiceps.*

TAENIA EXPANSA. See *Moniezia expansa* and *Thysanosoma actinioides.*

TAENIA FIMBRIATA. See *Thysanosoma actinioides.*

TAENIA HYDATIGENA:—*Ovis aries;* omentum and liver (larva): *Canis familiaris;* intestine (adult). Coll. and det. Curtice, 1886 and 1887, apparently at Colorado Springs and at Granger, near what is now the town of Falcon, from sheep. Reported by Curtice (1889 and 1890). Coll. and det. Hall, 1911, Resolis and Amo, from sheep (common); Kaupp, 1908-'11, Fort Collins, from sheep (common), and from dogs. The larval worm in the sheep is commonly known as *Cysticercus tenuicollis* and the adult worm in the dog as *Taenia marginata.* This adult worm may and very likely does occur in the coyote, but there are no actual records in support of this.

TAENIA MARGINATA. See *Taenia hydatigena.*

TAENIA PISIFORMIS:—*Lepus campestris, Sylvilagus auduboni baileyi;* body cavity and liver (larva). Coll. and det. Hall, 1911, Amo and Resolis, from rabbits (common); Kaupp, 1908-'11, Fort Collins, from rabbit (2 cases, genus and species of host not specified); coll. S. A. Johnson, 1903, Fort Collins, (from *Lepus campestris*), det. Ransom. The adult worm, commonly known as *Taenia serrata,* is usually reported from dogs, and the presence of the larval worm in rabbits is prima facie evidence that the adult worm occurs in dogs in this state.

TAENIA SAGINATA:—*Bos taurus;* heart (larva): *Homo sapiens;* intestines (adult). Det. Kaupp, 1908-'11, Fort Collins abattoir, 2 cases (from cow); coll. by physicians and det. by Kaupp, 1908-'11, Fort Collins, 3 cases (from man); coll. Dr. Geo. A. Boyd, 1911, Colorado Springs, det. Hall (1 case). The larval stage in the cow is known as *Cysticercus bovis.* The specimen collected by Dr. Boyd has gravid proglottids 3½ cm. long. The egg measurements are unusual, but the worm is assigned to *T. saginata* for the reason that this is a very variable species. Unfortunately the specimen is without a head.

TAENIA SOLIUM:—*Sus scrofa domestica;* heart (larva). Det.

Kaupp, 1908-'11, Fort Collins abattoir. 2 cases. Pfender (1910) finds almost no authentic cases of the adult tapeworm in man in the United States, although numerous specimens of the larval form, commonly known as *Cysticercus cellulosae,* in the hog show definitely that the adult worm occurs in man in this country. This lack of authentic records of the adult worm makes it highly desirable that cases of the larval worm in hogs be followed up if possible. In this case, Dr. Kaupp was unable to find where the hogs were from.

TAENIA SP.:—*Canis familiaris;* intestine. See *Multiceps multiceps.*

TAENIA SP.:—*Canis nebracensis;* intestine. Coll. and det. Hall, 1911, Amo.

TAENIA SP.:—*Erithizon epixanthum;* intestine. Coll. and det. Cockerell, 1887, Naomi. 1 case.

TAENIA SP.:—*Homo sapiens.* Coll. Dr. Webb. 1909, Colorado Springs, det. Stiles.

TAENIA SP.:—*Lepus sylvaticus;* intestine. Coll. and det. Curtice. Reported by Curtice (1892). The host species given does not occur in Colorado. It is specified as a cottontail and would be *Sylvilagus sp.* The generic name *Taenia* is used in a broad sense. There are no rabbit tapeworms of the genus *Taenia,* strictly speaking.

TAENIA SP:——*Lepus texianus;* intestine. Coll. and det. Curtice. Reported by Curtice (1892). See comment on foregoing species regarding use of *Taenia.*

TAENIA SP.:—*Lynx baileyi;* intestine. Coll. Ellis, 1911, Boulder, det. Hall.

TAENIA SP:—*Mephitis mephitica;* intestine. Reported by Stiles and Hassall (1894). According to Mr. Warren, this host should be either *M. hudsonica* or *M. mesomelas varians.*

TAENIA SP:—*Taxidea americana.* So listed by Stiles and Hassall. Warren (1910) uses *T. taxus* for the Colorado

badger.); intestine. Reported by Stiles and Hassall (1894).

TAENIA TENIAEFORMIS:—*Felis domestica;* intestine. Coll. Ellis, 1911, Boulder, det. Hall.

THYSANOSOMA ACTINIOIDES:—*Ovis aries;* gall and pancreatic ducts and duodenum. Coll. and det. Faville, Fort Collins; McEachran, Fort Collins; Curtice, 1886-'87, Granger and Colorado Springs; Hall and Ransom, 1911, Resolis and Amo; Hall, 1906 and 1911, Colorado Springs abattoir, in sheep from Resolis, Amo and Fountain; Kaupp, 1908-'11, Fort Collins; Dr. H. Busman, 1911, Denver abattoir in sheep from Oregon, Utah and Wyoming; Dr. Lamb, Carr. Faville's cases were reported by him in the report of the State Agricultural College for 1884, an article not available to me but cited by Curtice (1890). Under the name of *Taenia expansa,* Faville describes worms which are in part *Thysanosoma actinioides* and in part *Moniezia sp.* McEachran (1888) also describes *Thysanosoma* from sheep at the Agricultural College under the name of *Taenia expansa.* Crutice (1889 and 1890) made a study of this worm, for which he uses the synonym *Taenia fimbriata,* and of the disease caused by it, and we owe almost all of our knowledge of this important parasite to him. Most of his work was done around Granger, near the present town of Falcon. The writer and Dr. Ransom have found the worm very common in sheep in eastern Colorado and Dr. Kaupp has found it in 62 out of 65 sheep from northern Colorado. It is a parasite of considerable economic importance and scientific interest.

(III) NEMATHELMINTHA.

1. *NEMATODA.*

ASCARIS LUMBRICOIDES:—*Homo sapiens;* intestine and body cavity (this latter accidental and abnormal). Coll. and det. Garwood, Marshall; Perkins, Denver. Garwood (1907) records cases of 2 persons, recently arrived from France,

passing *Ascaris lumptricoides* (misspelling or printer's error) during an attack of typhoid. Perkins (1911) records operation for appendicitis where the appendix was found perforated by a lumbricoid worm, the worm being found crawling across the ascending colon.

ASCARIS EQUORUM:—*Equus caballus;* intestine. Coll. and det. Kaupp, 1908-'11, Fort Collins. 6 cases out of 41 postmortems.

ASCARIS SP:—*Mephitis mephitica;* intestine. Reported by Stiles and Hassall (1894). (See *Taenia sp.* for note on host name.)

ASCARIS SUUM:—*Sus scrofa domestica;* intestine. Coll. and det. Hall, 1906, Canon City; Hall, 1911, Denver abattoir (hogs said to be from Nebraska); Kaupp, 1908-'11, Fort Collins (common).

BELASCARIS SP:—*Canis nebracensis;* intestine. Coll. and det. Hall, 1911, Amo. 1 case.

BELASCARIS SP:—*Felis domestica;* intestine. Coll. Ellis, 1911, Boulder, det. Hall. 1 case.

BELASCARIS SP:—*Lynx baileyi;* intestine. Coll. Ellis, 1911, Boulder, det. Hall. 1 case.

CHABERTIA OVINA:—*Ovis aries;* large intestine. Coll. and det. Curtice. 1 case. Reported by Curtice (1890 and 1892) under the synonym *Sclerostomum hypostomum.*

CHABERTIA SP:—*Thomomys fossor;* cecum. Coll. and det. Hall, 1911, from alcoholic host material collected by Warren, 1909, Ruxton Creek near Colorado Springs, and 1910, Middle Brush Creek, Gunnison County, and Crested Buttes.

COOPERIA ONCOPHORA:—*Bos taurus*; intestine. Coll. and det. Hall, 1911, Colorado Springs abattoir from local dairy cattle. 1 case.

CYLICHNOSTOMUM CATINATUM:—*Equus caballus.* Coll. S. A. Johnson, 1907, Fort Collins, det. H. W. Graybill.

CYLICHNOSTOMUM SPP:—*Equus caballus;* cecum and colon.

Coll. and det. Hall, 1911, Colorado Springs (1 case); coll. S. A. Johnson, 1907, Fort Collins, det. H. W. Graybill.

CYLICHNOSTOMUM TETRACANTHUM:—*Equus caballus;* cecum and colon. Coll. Cockerell, 1888, West Cliffe; O'Brine, 1890, Fort Collins; coll. and det. Kaupp, 1908-'11, Fort Collins (22 cases out of 41 postmortems); Hall, 1911, Colorado Springs (1 case).

DIROFILARIA IMMITIS. See *Filaria immitis.*

FILARIA ATTENUATA:—*Sternella magna neglecta;* thoracic cavity. Coll. S. A. Johnson, 1903, Fort Collins, det. Ransom.

FILARIA CERVINA:—*Bos taurus*: body cavity. Coll. and det. Kaupp, 1908-'11, Fort Collins. 12 cases out of 18 postmortems. This should be called *Setaria labiato-papillosa.*

FILARIA IMITIS. See *Filaria immitis.*

FILARIA IMMITIS:—*Canis familiaris;* heart. Coll. and det. Van Meter, 1892, Denver. Reported by Van Meter (1892) as a case of *Filaria imitis* (misspelling). Dog had recently come from Arkansas and had doubtless acquired the infection there. *F. immitis* is now *Dirofilaria immitis* and type of the genus.

FILARIA PAPILLOSA:—*Equus caballus;* body cavity. Coll. and det. Kaupp, 1908-'11, Fort Collins. 36 cases out of 41 postmortems. This should be called *Setaria equina.*

FILARIA SP.:—*Asio wilsonianus;* subcutaneous in neck region. Coll. Duce and Rusk, Burnt Knoll, det. Hall. Reported by Cockerell (1911).

GONGYLONEMA SCUTATUM:—*Bos taurus;* oesophageal submucosa. Coll. and det. Hall, 1911, Denver abattoir (origin of cattle not ascertained) and Colorado Springs abattoir from local dairy cattle (3 cases out of 4 cows examined).

HABRONEMA MUSCAE:—*Musca domestica;* body cavity. Coll. and det. Ransom, 1911, Colorado Springs. Common. Reported by Ransom (1911). The presence of the adult worm in the stomach of the horse may be safely inferred from the presence of the larva in the fly.

HAEMONCHUS CONTORTUS:—*Ovis aries, Bos taurus, Capra hircus angoriensis;* fourth stomach. Coll. and det. Curtice, 1886, Granger (in Bureau of Animal Industry Collection) from sheep; Hall and Ransom, 1911, Resolis and Amo; Hall, 1911, Colorado Springs abattoir in sheep from Resolis, Amo and Fountain (common), in cattle from Colorado Springs dairies and from Monument, and in a goat from Amo (1 case). Curtice's collections are reported by Hall (1912). This parasite, known as the stomach worm of sheep, causes considerable loss to sheepmen in the eastern, southern and middle western states. In the dry plains of Colorado, conditions are not so favorable for its development, and while it is found in nearly all the sheep examined it nearly always occurs in such small numbers as to be of little or no economic importance. The greatest number the writer has yet found in a Colorado sheep was 536 and this was unusually large. In eastern sheep it is not uncommon to find thousands. West of the Mississippi, the stomach worm is supplanted by the fringed tapeworm, *Thysanosoma actinioides,* as a destructive parasite of prime economic importance.

HETERAKIS PAPILLOSA:—*Gallus gallus;* ceca. Coll. and det. Hall, 1911, Colorado Springs (3 cases); Kaupp, 1908-'11, Fort Collins (46 cases out of 87 postmortems).

HETERAKIS PERSPICILLUM:—*Gallus gallus;* intestine. Coll. and det. Hall, 1911, Colorado Springs (2 cases); Kaupp, 1908-'11, Fort Collins (24 cases out of 87 postmortems).

HOOKWORM:—*Homo sapiens;* intestine. An editorial in *Colorado Medicine* for December, 1909, says of pellagra and uncinariasis "The interest of Colorado physicians in these diseases is purely academic, no case of either having been reported in this state". It does not follow from the fact that there have been no reports of it that hookworm disease has only an academic interest for Colorado physicians. While conditions over much the greater part of the state are unfavorable to the development and spread of hook-

worm disease, there are, nevertheless, mines in this state, and especially in southern Colorado, where the disease might be looked for with a fair likelihood of finding it. Dr. Stiles tells me that a recent examination of some miners in Colorado failed to show any cases, but more investigation is necessary. Some of the mines offer satisfactory conditons for the development of the hookworm and only need the coming of a carrier to introduce it. That such carriers enter the state is beyond question. Dr. Webb of Colorado Springs had a hookworm patient from Tennessee during the summer of 1911. Diagnosis was made on the basis of the eggs in the feces and the worms passed subsequent to the administration of a dose of thymol. Unfortunately none of the worms were saved and it is impossible to say whether it was the hookworm of the Old or New World. It was probably the latter, *Necator americanus.*

MERMIS SP:—(Found on cabbage; parasitic in insects). Reported by Chittenden (1905). See Spurious parasites.

Nematode:—*Citellus elegans;* intestine. Coll. Hall, 1911, from alcoholic host material collected by Warren, 1911, Waldon.

Nematode:—*Citellus tridecemlineatus pallidus;* stomach. Coll. Hall, 1911, from alcoholic host material collected by Warren, 1910, Colorado Springs.

NEMATODE:—*Citellus t. pallidus;* small intestine. Coll. Hall, 1911, Amo.

Nematode:—*Citellus t. pallidus;* large and small intestine. Coll. Hall, 1911, Colorado Springs.

Nematode:—*Eleodes obsoleta;* body cavity (encysted). Coll. Hall, 1911, Colorado Springs.

Nematode:—*Taxidea americana.* (So labelled. Warren (1910) uses *T. taxus,* as already noted.) Coll. Curtice (?), 1886, Granger (Falcon). In Bureau of Animal Industry Collection.

Nematode:—*Thomomys fossor;* intestine. Coll. Hall, 1911,

from alcoholic host material collected by Warren, 1911, Livermore.

NEMATODIRUS FILICOLLIS:—*Ovis aries, Capra hircus angoriensis;* intestine. Coll. Hall, 1911, Amo (from sheep), det. Hall and Ransom (common); coll. and det. Hall, 1911, Colorado Springs abattoir in goat from Amo (1 case).

NEMATODIRUS SP:—*Eutamias quadrivitattus;* intestine. Coll. and det. Hall, 1911, from alcoholic host material collected by Warren, 1910, Crested Buttes.

NEMATODIRUS SP:—*Neotoma cinerea rupicola;* intestine. Coll. and det. Hall, 1911, from alcoholic host material collected by Warren and Durand, 1911, Pawnee Buttes.

OESOPHAGOSTOMUM RADIATUM:—*Bos taurus;* nodules in lower part of small intestine. Coll. and det. Hall, 1911, Colorado Springs abattoir in cow from Monument. 1 case.

OESOPHAGOSTOMUM SP.:—*Macacus rhesus;* large intestine. Coll. and det. Hall, 1911, Colorado Springs. The monkey, one of Dr. Webb's experiment animals, had been in this country 1 year and had probably brought this infection to this country with it.

OSTERTAGIA BULLOSA:—*Ovis aries;* fourth stomach. Coll. and det. Hall and Ransom, 1911, Resolis and Amo; Hall, 1911, Colorado Springs abattoir in sheep from Resolis. This parasite was first collected by the writer in sheep at Colorado Springs and was described as a new species by Ransom and Hall (1912).

OSTERTAGIA CIRCUMCINCTA:—*Ovis aries;* fourth stomach. Coll. Hall, 1911, Denver abattoir (in sheep from Wyoming and Utah), det. Hall and Ransom. Stomach contents sent by Dr. Busman.

OSTERTAGIA MARSHALLI:—*Ovis aries;* fourth stomach. Coll. Hall, 1911, Denver abattoir (in sheep from Wyoming and Utah), det. Ransom and Hall. Stomach contents sent by Dr. Busman.

OSTERTAGIA OCCIDENTALIS:—*Ovis aries;* fourth stomach. Coll.

Hall, 1911, Denver abattoir (in sheep from Wyoming), det. Hall and Ransom. Stomach contents sent by Dr. Busman.

OSTERTAGIA OSTERTAGI:—*Bos taurus;* fourth stomach. Coll. and det. Hall, 1911, Colorado Springs abattoir in cow from Monument. 1 case.

OXYURIS CURVULA:—*Equus caballus;* colon and rectum. Coll. and det. Kaupp, 1908-'11, Fort Collins (10 cases out of 41 postmortems); coll. S. A. Johnson, 1907, Fort Collins, det. H. W. Graybill; coll. and det. Hall, 1911, Colorado Springs (1 case).

OXYURIS OBVELATA:—*Mus musculus;* cecum. Coll. and det. Hall, 1911, Colorado Springs. Common.

OXYURIS SP.:—*Eutamias amoenus operarius;* cecum and large intestine. Coll. and det. Hall, 1911, Clyde. 3 cases out of 4 postmortems.

OXYURIS SP.:—*Eutamias quadrivittatus;* cecum and large intestine. Coll. and det. Hall, 1911, from alcoholic host material collected by Warren, 1910, Crested Buttes.

OXYURIS SP:—*Microtus mordaux;* cecum and large intestine. Coll. and det. Hall, 1911, from alcoholic host material collected by Warren, 1910, Crested Buttes.

OXYURIS SP.:—*Neotoma cinerea rupicola;* large intestine. Coll. and det. Hall, 1911, from alcoholic host material collected by Warren, 1911, Pawnee Buttes. 4 cases.

OXYURIS SP:—*Neotoma floridana baileyi;* large intestine. Coll. and det. Hall, 1911, from alcoholic host material collected by Warren, 1911, Cedar Point.

OXYURIS VERMICULARIS:—*Homo sapiens,* Fort Collins. Det. Kaupp, from a specimen sent in by physician.

PHYSALOPTERA ALATA:—*Accipiter velox;* stomach and intestine. Coll. S. A. Johnson, 1903, Fort Collins, det. Ransom.

PHYSALOPTERA TORQUATA:—*Taxidea taxus;* intestine. Coll. Dr. A. H. Dodge, 1911, Las Animas, det. Hall. In U. S. Naval Medical School Collection.

RICTULARIA SP.:—*Canis nebracensis;* intestine. Coll. and det. Hall, 1911, Amo. 1 case.

SCLEROSTOMUM HYPOSTOMUM. See *Chabertia ovina.*

SETARIA EQUINA. See *Filaria papillosa.*

SETARIA LABIATO-PAPILLOSA. See *Filaria cervina.*

SPIROPTERA OBTUSA:—*Mus musculus;* stomach. Coll. Hall, 1911, Colorado Springs (6 cases out of 6 postmortems), and Ellis, 1911, Boulder (1 case); det. Hall.

SPIROPTERA SP.:—*Citellus tridecemlineatus pallidus;* stomach. Coll. and det. Hall, 1911, Amo and Colorado Springs.

SPIROPTERA SP.:—*Cynomys ludovicianus;* stomach. Coll. and det. Hall, 1911, Resolis.

SPIROPTERA SP.:—*Sylvilagus auduboni baileyi;* stomach. Coll. and det. Hall, 1911, Resolis.

SPIROPTERA STRONGYLINA:—*Sus scrofa domestica;* stomach. Coll. and det. Hall, 1911, Denver abattoir in hogs said to be from Nebraska.

STRONGYLOIDES PAPILLOSUS:—*Ovis aries;* intestine. Coll. Ransom and Hall, 1911, Amo, det. Hall.

STRONGYLUS ARMATUS. See *Strongylus vulgaris.*

STRONGYLUS EDENTATUS:—*Equus caballus.* Coll. S. A. Johnson, 1907, Fort Collins, det. H. W. Graybill.

STRONGYLUS EQUINUS:—*Equus caballus;* cecum and colon. Coll. O'Brine, 1890, Fort Collins (In Bureau of Entomology Collection); coll. Hall, 1911, Colorado Springs, (1 case), det Ransom.

STRONGYLUS VULGARIS:—*Equus caballus;* cecum and colon. Coll. and det. Kaupp, 1908-'11, Fort Collins (38 cases out of 41 postmortems, 1 case in testis of cryptorchid, 1911); coll. Dr. Whitehouse, North Park, det. Kaupp (1 case in testis of cryptorchid); coll. Dr. Brocker, Steamboat Springs (1 case in testis of cryptorchid). Dr. Kaupp reports that 40 per cent. of the horses autopsied at Fort Collins have aneurisms of the anterior mesenteric artery, due to larval strongyles.

TRICHOSTRONGYLUS SP:—*Ovis aries;* intestine. Coll. Ransom and Hall, 1911, Amo, det. Hall.

TRICHURIS OVIS:—*Ovis aries;* cecum. Coll. and det. Hall,

1911, Resolis and at Colorado Springs abattoir in sheep from Resolis.

TRICHURIS SP.:—*Thomomys fossor;* cecum. Coll. and det. Hall, 1911, from alcoholic host material collected by Warren, 1910, Crested Buttes, and 1911, Livermore.

TROPIDOCERCA SP.:—*Bufo virginianus.* Collected in 1893. In National Museum Collection.

TOXOCARA CANIS:—*Canis familiaris;* intestine. Coll. and det. Kaupp, 1908-'11, Fort Collins.

TOXOCARA SP:—*Canis familiaris;* intestine. Coll. and det. Hall, 1911, Colorado Springs. 1 case.

TOXOCARA SP.:—*Felis domestica;* intestine. Coll. Hall, 1904, Colorado Springs, det. Hall. (Specimens not preserved. Impossible to refer them to the later genera *Belascaris* and *Toxascaris.*)

2. *ACANTHACEPHALA.*

ECHINORHYNCHUS HIRUDINACEOUS:—*Sus scrofa domestica;* intestine. Coll. and det. Kaupp, 1908-'11, Fort Collins (common); Hall, 1911, Denver abattoir in hog said to be from Nebraska,(1 case).

3. *GORDIACEA.*

Gordius lineatus:—Host (?). Coll. and det. Hall, 1906, Little Fountain Creek (south of Colorado Springs) and St. Peters.

Gordius longareolatus:—Host (?). Coll. and det. Hall, 1906, St. Peters.

Gordius sp.:—Host (?). Coll. W. A. Hammond, 1857 (?), Western Colorado, det. Leidy. Reported by Leidy (1857) as collected 525 miles west of Fort Riley, Kansas. This would be somewhere in western Colorado.

Gordius sp.:—Host (?). Coll. and det. Hall, 1906, St. Peters.

Gordius sp.:—Host (?). Coll. and det. Hall, 1906, Rock Creek (south of Colorado Springs).

(IV.) ANNULATA.

1. *HIRUDINEA.*

PLACOBDELLA RUGOSA:—Host (?). Coll. Hall, 1907, Canon City, det. J. Percy Moore.

ERPOBDELLA PUNCTATA:—Host (?). Coll. Hall, 1907, Canon City, det. J. Percy Moore.

(V.) ARTHROPODA.

1. *CRUSTACEA.*

ACHTHERES or LERNAEOPODA:—Trout; mouth and gills. Coll. D. C. Beaman, Denver (?). In Dr. Ward's collection.

Dr. Charles Branch Wilson informs me that he knows of no parasitic copepods from Colorado, and has no records of any in MS. notes of G. G. Gurley, Richard Rathbun, M. T. Thompson or Edwin Linton. Dr. Harriet Richardson tells me that she knows of no parasitic isopods from Colorado.

2. *INSECTA.*

(1.) *PLATYPTERA.*

COLPOCEPHALUM ASSIMILE:—Whooping crane (*Grus americana*, per Kellogg 1900); skin. Coll. and det. Gillette, Lamar. Reported by Osborn (1896).

COLPOCEPHALUM LATICEPS:—*Botaurus lentiginosus;* skin. Coll. A. C. Stephenson, Fort Collins. Reported by Osborn (1902).

DOCOPHORUS DISTINCTUS:—*Corvus corax sinuatus;* skin. Reported by Kellogg (1900).

DOCOPHORUS SIALLII:—*Sialia sialis;* skin. Kellogg (1900) lists this from "Merriam, Colo." and refers it to Osborn (1896). Osborn, however, in his description of this new species refers it to "Merriam Coll.", presumably an abbreviation of "Merriam Collection." There is no record from Colorado, as far as the writer is aware.

DOCOPHORUS SP.:—*Asio flammeus;* skin. Coll. and det. Cockerell, 1910, Boulder County.

DOCOPHORUS SP.:—*Cynomys ludovicianus;* skin. Coll. and det. Hall, 1911, Natural Corral, El Paso County. Insects of this genus are obviously errant when found on hosts other than birds. The probable true host of this insect is *Speotyto cunicularia hypogaea,* but the parasite is not *D. speotyti.*

DOCOPHORUS SPEOTYTI:—*Speotyto cunicularia hypogaea;* skin. Coll. C. F. Baker, Fort Collins; described as a new species by Osborn (1896).

LIPEURUS DOCOPHOROIDES:—*Gallus gallus;* skin. Coll. Chas. Euler, 1907, Boulder; det. Kellogg. (Data from Cockerell).

MENOPON BISERIATUM:—*Gallus gallus;* skin. Coll. and det. Kaupp, 1908-'11, Fort Collins (common).

MENOPON PALLIDUM:—*Gallus gallus;* skin. Coll. and det. Kaupp, 1908-'11, Fort Collins (common); coll. Cockerell, 1888, West Cliffe.

PHYSOSTOMUM HASTATUM:—*Junco hyemalis oregonus;* skin Coll. A. C. Stephenson, Fort Collins. Described as a new species by Osborn (1902).

PHYSOSTOMUM SP.:—Song sparrow; skin. Coll. H. de W. Betts, 1910, Boulder; det. Cockerell.

TRICHODECTES LIMBATUS:—*Capra hircus angoriensis;* skin. Coll. and det. Hall, 1911, Colorado Springs in goat from Amo. 1 case.

TRICHODECTES MEPHITIDIS:—*Taxidea taxus;* skin. Coll. J. A. Rowher, 1907, from badger collected by Warren near Jefferson; det. Cockerell.

TRICHODECTES PILOSUS:—*Equus caballus;* skin. Coll. and det. Kaupp, 1909, northern Colorado. 1 case.

(2.) *HEMIPTERA.*

ACANTHIA LECTULARIA:—*Homo sapiens;* skin. Coll. and det. Hall, 1911, Colorado Springs. This widely distributed parasite, the bedbug, is getting increasing attention as the carrier of diseases.

HAEMATOPINUS ASINI:—*Equus caballus;* skin. Coll. and det. Kaupp, 1911, northern Colorado. 1 case.

HAEMATOPINUS MONTANUS:—Western gray squirrel; skin. Coll. Baker, Fort Collins; described as a new species by Osborn (1896).

HAEMATOPINUS PEDALIS:—*Ovis aries;* skin. Coll. and det. Kaupp, 1908-'11, Fort Collins. 1 case.

HAEMATOPINUS SP.:—*Eutamias amoenus operarius;* skin. Coll. and det. Hall, 1911, Clyde.

HAEMATOPINUS SUIS:—*Sus scrofa domestica;* skin. Coll. and det. Kaupp, 1908-'11, Fort Collins. Common.

PEDICULUS CAPITIS:—*Homo sapiens;* in hair of head. The writer recalls seeing this in Denver in 1887 and knew of several cases in Colorado Springs about 1898. In the last case, the lice were spread among pupils at school, apparently by the general use of a comb kept in the girls' cloak room. The individual comb is, of course, practically as desirable as the individual drinking cup, and for much the same reasons.

(3.) *DIPTERA.*

AEDES CURRIEI:—Host (?). Coll. E. P. Taylor, 1906, Grand Junction; Cockerell, Florissant; S. A. Rohwer, 1907, Florissant; det. Dyar and Knab. Recorded from Grand Junction by Dyar (1907).

AEDES NIGROMACULIS:—Host (?). Coll. H. L. Shantz, 1909, Akron; S. A. Rohwer, 1907, Boulder; det. Dyar and Knab.

AEDES SP.:—Host (?). Coll. C. Dwight Marsh, 1910, Mount Carbon, det. Knab.

AEDES SYLVESTRIS:—Host (?). Coll. E. P. Taylor, 1906, Grand Junction; Cockerell, Boulder; det. Dyar and Knab. See *Culex stimulans.*

ANOPHELES SP.:—[*Homo sapiens.*] Coll. G. P. Weldon, 1911, Delta County, according to letter from Professor Gillette. This record is very important. See *Plasmodium sp.*

CALLIPHORA VIRIDESCENS:—Host (?). Coll. C. Dwight Marsh, 1910, Mount Carbon, det. Coquillet.

CALLIPHORA VOMITORIA:—Host (?). Coll. C. Dwight Marsh, 1910, Mount Carbon, det. Coquillet.

CERATOPOGON COCKERELLII:—Host (?). Coll. Cockerell, Custer County. Described as a new species by Coquillett (1901).

CERATOPOGON SPECULARIS:—Host (?). Described as a new species, partly on Colorado material, by Coquillett (1901).

CHRYSOPS CARBONARIUS:—Host (?). Recorded by Hine (1904).

CHRYSOPS COLORADENSIS:—Host (?). Recorded by Hine (1904).

CHRYSOPS COQUILETTII:—Host (?). Recorded by Hine (1904) p. 246. Apparently an error as p. 221 specifies California exclusively and apparently correctly.

CHRYSOPS DISCALIS:—Host (?). Recorded by Hine (1904).

CHRYSOPS FULVASTER:—Host (?). Coll. Titus, 1904, Delta, det. Coquillet. A record by Hine (1904) may be based on Titus's record in the Bureau of Entomology.

CHRYSOPS LUPUS:—Host (?). Recorded by Hine (1904).

CHRYSOPS VITTATUS:—*Bos taurus;* skin. Coll. and det. Kaupp, 1908-'11, in mountains around Fort Collins. Common.

CULEX CONSOBRINUS:—Host (?). Det. Coquillet. Reported by Howard (1900). The correct name of this species is *Culiseta inornatus* q. v.

CULEX STIMULANS:—Host (?). Det. Coquillet. Reported by Howard (1900). The correct name of this species is *Aedes sylvestris,* q. v.

CULEX TARSALIS:—Host (?). Coll. S. A. Rohwer, 1907, Florissant; E. P. Taylor, 1906, Grand Junction; E. S. Tucker, Denver; det. Dyar and Knab.

CULISETA INCIDENS:—Host (?). Coll. at Burke; coll. E. P. Taylor, 1906, Plateau Canon; det. Dyar and Knab.

CULISETA INORNATUS:—Host (?) Coll. Cockerell, 1908, Boulder, det. Dyar; coll. S. A. Rohwer, 1907, Florissant; E. S. Tucker, Denver: det. Dyar and Knab. See *Culex consobrinus.*

CULISETA SP.:—Host (?). Coll. C. Dwight Marsh, 1910, Mount Carbon, det. Knab.

CUTEREBRA AMERICANA:—Host (?). Adult fly coll. and det. Gillette, 1893 and 1897, Fort Collins. Also collected in Fort Collins in 1909 according to letter from Professor Gillette.

CUTEREBRA CUNICULI:—Rabbit; subcutaneous. Estes Park. Reported by Osborn (1896).

CUTEREBRA LEPIVORA:—Host (?). Recorded by Swenk (1905).

CUTEREBRA LEPUSCULI:—Host (?). Coll. O. G. Babcock, 1910, Fort Collins, according to letter from Professor Gillette.

CUTEREBRA SP.:—*Citellus tridecemlineatus pallidus;* subcutaneous. Coll. H. M. Ragle, 1911, Golden; det. Hall.

CUTEREBRA SP.:—*Neotoma fallax* (?); subcutaneous. Coll. Young, 1902, Boulder, det. Hall.

CUTEREBRA TENEBROSA:—Host (?). Recorded by Swenk (1905).

Fly larvae:—*Homo sapiens;* subcutaneous. Coll. Drs. Wm. C. Mitchell, H. B. Whiting, and E. P. Hershey. Mitchell (1905) reported 3 cases of fly larvae in man. Dr. Whiting, in the discussion of the paper before the Denver Academy of Medicine, reported 1 additional case and Dr. Hershey 2 additional cases. The abstract does not state definitely that the cases occurred in Colorado, though the presumption is that they did. The nature of the infection suggests that these are additional cases of *Paralucilia macellaria,* q. v.

GASTROPHILUS EQUI:—*Equus caballus;* stomach. Coll. D. O'Brine, 1890, Fort Collins; coll. and det. E. G. Titus, 1897, Fort Collins, according to letter from Professor Gillette (larva found in stable); Kaupp, 1908-'11, Fort Collins (6 cases out of 41 postmortems); Hall, 1911, Colorado Springs (1 case); Gillette has collected the adult fly at Craig.

GASTROPHILUS HAEMORRHOIDALIS:—*Equus caballus;* stomach.

Coll. and det. Kaupp, 1908-'11, Fort Collins. 35 cases out of 41 postmortems. Gillette has collected the adult fly from unspecified locality in Colorado.

GASTROPHILUS NASALIS:—*Equus caballus;* stomach. Coll. and det. Hall, 1911, Colorado Springs (1 case); adult fly coll. and det. Gillette, 1902 and 1909, Fort Collins, and 1903, Greeley; adult fly coll. and det. S. A. Johnson, 1904, Steamboat Springs, according to letter from Professor Gillette.

HAEMATOBIA SERRATA:—*Bos taurus;* skin. Coll. and det. Kaupp, 1908-'11, Fort Collins. Common.

HAEMATOPOTA AMERICANA:—Host (?). Recorded by Hine (1904).

HYPODERMA LINEATA:—*Bos taurus;* subcutaneous. Coll. W. L. Campbell, 1884, Denver; coll. and det. Hall, 1901, Amo (1 case); Kaupp, 1908-'11, Fort Collins (common). The adult fly has been collected at Siebert, and also by Crawford Moore, 1905, at Yuma, according to letter from Professor Gillette.

MELOPHAGUS OVINUS:—*Ovis aries;* skin. Coll. and det. Kaupp, 1908-'11, Fort Collins (common); Hall, 1911, Resolis, Amo, and Colorado Springs abattoir on sheep from these 2 places (common). This parasite commonly known as the sheep tick, is cosmopolitan and apparently does some little damage here as elsewhere.

NYCTERIBIA SP.:—*Myotis evotis;* skin. Coll. Warren, 1911, Steamboat Springs; det. Banks.

OESTRUS OVIS:—*Ovis aries;* nasal passages and frontal sinuses. Coll. and det. Kaupp, 1908-'11, Fort Collins (common); Hall, 1911, Resolis, Amo, and Colorado Springs abattoir in sheep from these 2 places; adult fly coll. and det. E. G. Titus, 1900, Fort Collins, and reared from grub by Gillette, 1897, Fort Collins, acording to letter from Professor Gillette. In its larval stage this parasite is known as "grub in the head". It does considerable damage in the United States, including some Rocky Mountain states, but it has

not been reported as causing serious trouble in Colorado and the writer has not yet found a severe infection in this state.

PARALUCILIA MACELLARIA:—*Homo sapiens;* nostril, ear and subcutaneous. Coll. R. W. Corwin, 1908, Pueblo (from nostril of Italian woman); Chauncey E. Tennant, 1905, Denver (from ear and subcutaneous on the side of neck of a child); Gillette, 1905, Fort Collins (from ear of hospital patient): det. Coquillet. This fly or its larva, the latter being commonly known as the "screw worm", is reported by writers under a number of scientific names, the one given here being the preferred one, according to Mr. Knab. Infections not infrequently end in the death of the host, though apparently none of the Colorado cases terminated fatally, judging from the data available in these records which are in the files of the Bureau of Entomology. See also cases of myiasis noted under "Fly larvae".

PANGONIA INCISA:—Host (?). Recorded by Hine (1904).

SARCOPHAGA SP:—Grasshopper. Coll. A. C. Maxson, 1911, Longmont, det. Walton. Apparently responsible for the death of many grasshoppers.

SARCOPHAGA SP:—Host (?). Coll. G. W. Martin, 1900, Sterling. In Bureau of Entomology Collection.

SILVIUS GIGANTULUS:—Host (?). Recorded by Hine (1904).

SILVIUS POLLINOSUS:—*Homo sapiens;* skin. Coll. Hall, 1911, Resolis, det. Knab. Also recorded by Hine (1904).

SIMULIUM FULVUM:—Host (?). Recorded by Coquillet (1902).

STOMOXYS CALCITRANS:—*Homo sapiens;* skin. Coll. Hall, 1911, Resolis, det. Knab.

TABANUS ATRATUS:—*Bos taurus;* skin. Coll. and det. Kaupp, 1908-'11, Fort Collins. Common.

TABANUS CENTRON:—Host (?). Recorded by Hine (1904).

TABANUS COFFEATUS:—Host (?). Recorded by Hine (1904).

TABANUS EPISTALUS:—Host (?). Recorded by Hine (1904).

TABANUS INSUETUS:—Host (?). Recorded by Hine (1904).

TABANUS INTENSIVUS:—Host (?). Recorded by Hine (1904).

TABANUS LINEOLA:—*Bos taurus;* skin. Coll. and det. Kaupp, 1908-'11, Fort Collins. Common. Recorded by Hine (1904) also.

TABANUS PHAENOPS:—Host (?). Recorded by Hine (1904).

TABANUS PUNCTIFER:—Host (?). Recorded by Hine (1904).

TABANUS REINWARDTII:—Host (?). Coll. Dr. F. H. Snow, Estes Park and Manitou Park; E. J. Oslar, Southwestern Colorado. Recorded by Hine (1904).

TABANUS RHOMBICUS:—Host (?). Recorded by Hine (1904).

TABANUS SEPTENTRIONALIS:—Host (?). Coll. C. Dwight Marsh, 1910, Mount Carbon, det. Coquillet.

TABANUS SONOMENSIS:—Host (?). Coll. C. Dwight Marsh, 1910, Mount Carbon, det. Coquillet.

TANYPUS OCCIDENTALIS:—Host (?). Coll. Cockerell, Custer County. Described as a new species by Coquillet (1902).

TRICHOBIUS CORYNORHINI:—*Corynorhinus macrotis pallescens;* skin. Coll. Cockerell, Great Sphinx Mine. Described as a new species by Cockerell (1910).

(4.) *SIPHONAPTERA.*

CERATOPHYLLUS BACCHI:—*Citellus tridecemlineatus pallidus:* skin. Coll. and det. Hall, 1911, Amo and Natural Corral, El Paso County.

CERATOPHYLLUS BRUNERI:—*Citellus tridecemlineatus* (More accurately, *C. t. pallidus*); skin. Coll. Baker, Fort Collins. Described as a new species, partly on Colorado material, by Baker (1895) under the name of *Pulex bruneri.* Transferred to the genus *Ceratophyllus* by Wagner (1898).

CERATOPHYLLUS COLORADENSIS:—*Sciurus fremonti;* skin. Coll. Bruner, Georgetown. Described as a new species by Baker (1895) under the name of *Pulex coloradensis.* Transferred to the genus *Ceratophyllus* by Wagner, (1898).

CERATOPHYLLUS DIVISUS:—*Sciurus fremonti;* skin. Coll. Bruner, Georgetown. Described as a new species by

Baker (1895) under the name of *Pulex longispinus*. This name was preoccupied, and hence the species was renamed by Baker (1898) as *Pulex divisus*. It was subsequently transferred to the genus *Ceratophyllus* by Baker (1904).

CERATOPHYLLUS HIRSUTUS:—*Citellus elegans, Cynomys ludovicianus;* skin. Coll. Gillette, from prairie-dog. Described as a new species by Baker (1895) under the name of *Pulex hirsutus.*. Transferred to the genus *Ceratophyllus* by Wagner (1898). Coll. and det. Hall, 1911, from prairie-dog, Resolis and at Natural Corral, El Paso County; coll. Warren, 1911, from picket-pin gopher, Waldon, det. Hall.

CERATOPHYLLUS IGNOTUS:—*Geomys bursarius* (So listed by Baker. Warren (1910) states that the only Colorado form is *G. lutescens.*), *Thomomys talpoides* (So listed by Baker. Warren (1910) makes the Colorado form *Th. t. agrestis.*); skin. Coll. Baker, Fort Collins. Described as a new species by Baker (1895) under the name of *Pulex ignotus*, and later (Baker, 1895) as *Typhlopsylla americana.* Transferred to the genus *Ceratophyllus* by Wagner (1898).

CERATOPHYLLUS LUCIDUS:—*Sciurus fremonti;* skin. Coll. Baker, 1899, Pagosa Peak. Described as a new species by Baker (1904).

CERATOPHYLLUS MONTANUS:—*Sciurus aberti, Citellus variegatus grammurus;* skin. Coll. J. D. Stannard on Abert's squirrel, "Foothills west of Fort Collins." According to Mr. Warren, the host in this locality would be *S. aberti ferreus.* Described as a new species by Baker (1895) under the name of *Pulex montanus.* Transferred to the genus *Ceratophyllus* by Wagner (1898). Coll. and det. Baker, Arboles, on rock squirrel; coll. Warren, 1909, Colorado Springs, on rock squirrel, det. Rothschild.

CERATOPHYLLUS SP.:—*Callospermophilus* or *Eutamias* (Specimens mixed in collection or in transit.); skin. Coll. War-

ren, 1909, det. Rothschild. The writer has found *Ceratophyllus* on *Eutamias* but not on *Callospermophilus.*

CERATOPHYLLUS SP.:—*Citellus tridecemlineatus pallidus;* skin. Coll. and det. Hall, 1911, Colorado Springs and Natural Corral, El Paso County.

CERATOPHYLLUS SPP.:—*Eutamias amoenus operarius;* skin Coll. and det. Hall, 1911, Clyde.

CERATOPHYLLUS SP.:—*Marmota flaviventer;* skin. Coll. Warren, 1911, Chamber's Lake, det. Hall.

CERATOPHYLLUS SPP.:—*Neotoma cinerea orolestes;* skin. Coll. Warren, 1911, Buffalo Pass Sawmill, det. Hall.

CERATOPHYLLUS SP.:—*Neotoma fallax;* skin. Coll. Warren, 1909, Colorado Springs, det. Rothschild.

CERATOPHYLLUS SP.:—*Ochotona saxatilis;* skin. Coll. Warren, 1910, Gunnison County, det. Hall.

CERATOPHYLLUS SP.:—*Putorius arizonensis;* skin. Coll. Warren, 1911, Steamboat Springs, det. Hall.

CERATOPSYLLUS CROSBYI:—*Myotis evotis;* skin. Coll. Warren, 1911, Steamboat Springs, det. Hall.

CTENOCEPHALUS INAEQUALIS:—*Lepus sp.;* skin. Coll. and det. Baker, Arboles. Reported by Baker (1904).

CTENOCEPHALUS CANIS:—*Canis familiaris;* skin. Coll. and det. Kaupp, 1908-'11, Fort Collins. This flea, commonly recorded under its synonym, *Pulex serraticeps,* is found as a parasite of man in this country more often than is *Pulex irritans,* the flea which in Europe attacks man as its primary host.

CTENOCEPHALUS CANIS (?):—Host (?). Coll. Cockerell, Swift Creek, Custer County, det. L. O. Howard.

CTENOPSYLLUS ALPINUS:—*Neotoma sp.;* skin. Coll. Bruner, Georgetown. Described as a new species by Baker (1895) under the name of *Typhlopsylla alpina.* Transferred to the genus *Ctenopsyllus* by Wagner (1898).

HOPLOPSYLLUS AFFINIS:—*Sylvilagus auduboni baileyi;* skin. Coll. and det. Hall, 1911, Colorado Springs.

HOPLOPSYLLUS ANOMALUS:—*Citellus sp.; skin.* Coll. Baker,

1899, Arboles. Described as a new species by Baker (1904) under the name of *Pulex anomalus*. Transferred to the genus *Hoplopsyllus* by Baker (1905).

HOPLOPSYLLUS SP.:—*Lepus campestris;* skin. Coll. and det. Hall, 1911, Resolis.

HOPLOPSYLLUS SP.:—*Sylvilagus auduboni baileyi;* skin. Coll. and det. Hall, 1911, Amo.

PULEX ANOMALUS. See *Hoplopsyllus anomalus.*

PULEX COLORADENSIS. See *Ceratophyllus coloradensis.*

PULEX DIVISUS. See *Ceratophyllus divisus.*

PULEX HIRSUTUS. See *Ceratophyllus hirsutus.*

PULEX IGNOTUS. See *Ceratophyllus ignotus.*

PULEX LONGISPINUS. See *Ceratophyllus divisus.*

PULEX MONTANUS. See *Ceratophyllus montanus.*

PULEX SCIURI (?). Host (?). Coll. Cockerell, Short Creek, Custer County, det. L. O. Howard.

PULEX SERRATICEPS. See *Ctenocephalus canis.*

SPILOPSYLLUS SP.:—*Sylvilagus auduboni baileyi;* skin. Coll. and det. Hall, 1911, Resolis and Amo.

TYPHLOPSYLLA ALPINA. See *Ctenocephalus alpinus.*

TYPHLOPSYLLA AMERICANA. See *Ceratophyllus ignotus.*

3. *ARACHNIDA.*

(1.) *ACARINA.*

IXODES SP.:—*Homo sapiens, Putorius arizonensis;* skin. Coll. Warren, 1911, Steamboat Springs, det. Banks. Nymphs. Occurrence on man by accidental transfer.

CNEMIDOCOPTES MUTANS:—*Gallus gallus;* skin. Coll. and det. Kaupp, 1908-'11, Fort Collins. Occasional. This is the cause of "scaly leg" in chickens.

DEMODEX FOLLICULARUM:—*Sus scrofa domestica;* follicles of skin. Coll. and det. Kaupp, 1908-'11, Fort Collins. 1 case, entire body involved.

DERMACENTOR AMERICANUS:—*Homo sapiens;* neck. Fort Collins. Recorded by Banks (1895). This is the species

which Banks now calls *D. venustus,* q. v., and which Stiles calls *D. andersoni.*

DERMACENTOR ANDERSONI. See *D. venustus.*

DERMACENTOR RETICULATUS:—*Bos taurus, Equus caballus;* skin. Det. Kaupp, 1908-'11, 2 cases. Specimens sent in from eastern Colorado.

DERMACENTOR VARIABILIS:—Host (?). Coll. Cockerell, 1911, Tolland; det. Banks.

DERMACENTOR VENUSTUS:—*Homo sapiens,* (?) *Neotoma cinerea orolestes, et al.* Reported from man by Banks (1895) from Fort Collins under name of *D. americanus,* q. v.; by Banks (1908) and Stiles (1910) from Fort Collins and Boulder; by Cockerell (1911) from Boulder County; by Bishopp (1911) from Colorado; by Hunter and Bishopp (1911) from Boulder, Clear Creek, Eagle, Garfield, Gunnison, Jefferson, Larimer, Mesa, Pitkin and Summit Counties. A *Dermacentor* nymph, probably of this species from *Neotoma c. orolestes,* coll. Warren, 1911, Log Cabin, det. Banks. This tick, called by Stiles *D. andersoni,* is the carrier of Rocky Mountain spotted fever.

DERMANYSSUS GALLINAE:—*Gallus gallus;* skin. Coll. A. Cameron, Fort Collins. Recorded by Banks (1895). Coll. F. G. Pabor, 1909, Boulder; Hall, 1911, Resolis: det. Banks.

HAEMAPHYSALIS CHORDEILIS:—Killdeer; skin. A nymph collected at Fort Collins is reported by Banks (1908) as possibly belonging to this species.

HYLETASTES. See *Iphis sp.*

IPHIS SP.:—Host (?). Coll. Gillette, Fort Collins. Recorded by Banks (1895). According to Banks (1904), the correct name of this genus is *Hyletastes.*

IXODES ANGUSTUS (?):—*Ochotona saxatilis;* skin. Coll. Warren, 1911, Gunnison County, det. Hall.

IXODES COOKEI:—"Small mammals"; skin. Reported by Banks (1908) from Denver.

IXODES MARXI:—Fox; skin. Reported from Denver by Banks

(1908). The article describes this as a new species but does not give the locality of the type specimens. The hosts are said to be red squirrels in the eastern United States.

LAELAPS SP.:—Host (?). Coll. Gillette, Fort Collins. Recorded by Banks (1895).

LAMINOSIOPTES CYSTICOLA:—*Gallus gallus;* subcutaneous. Coll. E. Grant, 1911, Denver, det. Ransom.

LIPONYSSUS SP.:—*Citellus tridecemlineatus pallidus;* skin. Coll. and det. Hall, 1911, Natural Corral, El Paso County.

MACROCHELES SP.:—*Aphodius coloradensis, Aphodius vittatus;* on thorax. Coll. Hall, 1911, Amo, det. Banks.

MICROTROMBIDIUM LOCUSTARUM:—(Grasshoppers). Coll. W. P. Cockerell, 1907, Boulder, det. Banks. Reported by Cockerell (1911).

ORNITHODOROS MEGNINI:—*Bos taurus;* ears. Coll. Tom Swain, 1908, Paradox, det. Hassall; det. Kaupp, 1908-'11, from specimens sent in from eastern Colorado; reported by Hunter and Bishopp (1911b) from southern Colorado.

PIGMEOPHORUS SP.:— *Canthon chalortes;* on abdomen under elytra. Coll. Hall, 1911, Amo, det. Banks.

PSOROPTES COMMUNIS BOVIS:—*Bos taurus;* skin. All of the counties in eastern Colorado, as far west as the eastern part of Weld, Adams, Arapahoe, Elbert, Lincoln, El Paso, Pueblo, Huerfano and Las Animas Counties, are under federal quarantine for cattle scab.

PSOROPTES COMMUNIS OVIS:—*Ovis aries, Ovis canadensis;* skin. A number of the southern counties in Colorado are still under federal quarantine for sheep scab, caused by this parasite. (See Map. fig. 1). Warren (1910) records that 75 Mountain sheep or Bighorn were found dead of this disease at one time at the head of Sapinero Creek, having been infected from bands of domestic sheep.

PSOROPTES (?):—*Eutamias amoenus operarius;* skin. Coll. and det. Hall, 1911, Clyde.

RHIPICEPHALUS SP.:—Killdeer (misprinted as Kittdeer). Coll. R. C. Stephenson, Fort Collins. Recorded by Banks

(1895). Later referred to by Banks (1908) as *Haemaphysalis chordeilis*, q. v.

Sarcoptid mite:—*Eutamias amoenus operarius;* skin. Coll. Hall, 1911, Clyde.

TRICHOTARSUS SP.:—*Osmia leonis.* Coll. Edna Baker, Boulder, det. Banks. Reported by Cockerell (1911).

TROMBIDIUM HOLOSERICEUM:—*Gallus gallus;* skin. Coll. and det. Kaupp, 1908-'10, Fort Collins. Very common.

TYROGLYPHUS SP.:—*Listrochelus fimbripes;* under elytra and on thorax. Coll. Hall, 1911, Amo, det. Banks.

(VI.) SPURIOUS PARASITES.

In the parasite collection of the Bureau of Animal Industry, there are two specimens of spurious parasites collected by physicians in Denver and sent in to the Bureau for identification as parasites. One of these was found to consist of fragments of earthworm and the other was an insect larva. The larva was determined by Dr. Chittenden of the Bureau of Entomology as *Tenebrio obscurus.* Both specimens were said to have been collected in human feces. Probably their presence there was due to accident or some hysterical patients had swallowed these things and they had passed the alimentary canal without digesting. Chittenden (1905) reports cases where the presence of a hairworm, *Mermis sp.*, [or, perhaps, *Gordius*], found in cabbage from some place in Colorado resulted in the destruction of the cabbage, during a scare over this so-called "cabbage snake". These worms are parasitic in insects and their occasional presence in man is probably due to swallowing the worms in drinking water. The writer has collected from the intestine of *Macacus rhesus* the banana fibers which were first described by Stiles and Hassall (1902) as a spurious parasite of man.

III. COMPENDIUM OF THE PARASITES LISTED IN THIS PAPER ARRANGED ACCORDING TO THEIR HOSTS.

(I.) CHORDATA.

1. *MAMMALIA.*

(1.) *PRIMATES.*

HOMO SAPIENS:—*Acanthia lectularia, Anopheles sp., Ascaris lumbricoides,* Cestode, *Cytoryctes variolae, Dermacentor andersoni* seu *venustus, Dibothriocephalus latus, Echinococcus granulosus,* Fly larvae, Hookworm, *Ixodes sp., Neuroryctes hydrophobiae, Oxyuris vermicularis, Paralucilia macellaria, Pediculus capitis, Plasmodium sp., Silvius pollinosus, Stomoxys calcitrans, Taenia saginata, Taenia sp., Treponema pallida.*

MACACUS RHESUS:—*Œsophagostomum sp.*

(2.) *CARNIVORA.*

CANIS FAMILIARIS:—*Ctenocephalus canis, Dipylidium caninum, Filaria immitis,* (?) *Multiceps multiceps, Neuroryctes hydrophobiae, Taenia hydatigena, Taenia sp., Toxocara canis, Toxocara sp.*

CANIS NEBRACENSIS:—*Belascaris sp., Rictularia sp., Taenia sp.*

CANIS OCCIDENTALIS:—(?) *Neuroryctes hydrophobiae.*

FELIS DOMESTICA:—*Belascaris sp., Dipylidium caninum,* (?) *Neuroryctes hydrophobiae, Taenia teniaeformis, Toxocara sp.*

FOX:—*Ixodes marxi.*

LYNX BAILEYI:—*Belascaris sp., Taenia sp.*

MEPHITIS HUDSONICA. See *M. mephitica.*

MEPHITIS MEPHITICA (This should be either *M. hudsonica* or *M. mesomelas varians.*):—*Ascaris sp., Taenia sp.*

MEPHITIS MESOMELAS VARIANS. See *M. mephitica.*

PUTORIUS ARIZONENSIS:—*Ceratophyllus sp., Ixodes sp.*

TAXIDEA AMERICANA. See *T. taxus.*

TAXIDEA TAXUS:—Nematode, *Pyhsaloptera torquata, Taenia sp., Trichodectes mephitidis.*

(3.) *RODENTIA.*

CALLOSPERMOPHILUS LATERALIS:—Cestode.

CALLOSPERMOPHILUS SP.:—*Ceratophyllus sp.*

CITELLUS ELEGANS:—*Ceratopyhllus hirsutus,* Nematode.

CITELLUS SP.:—*Hoplopsyllus anomalus.*

CITELLUS TRIDECEMLINEATUS PALLIDUS:—*Ceratophyllus bacchi, Ceratophyllus bruneri, Ceratophyllus sp.,* Cestode, *Cuterebra sp., Liponyssus sp.,* Nematode, *Spiroptera sp.*

CITELLUS VARIEGATUS GRAMMURUS:—*Ceratophyllus montanus.*

CYNOMYS LUDOVICIANUS:—*Ceratophyllus hirsutus, Ceratophyllus sp., Docophorus sp., Hymenolepis sp., Spiroptera sp.*

ERITHIZON EPIXANTHUM:—*Taenia sp.*

EUTAMIUS AMOENUS OPERARIUS:—*Ceratophyllus spp., Haematopinus sp., Oxyuris sp., Psoroptes* (?), Sarcoptid mite.

EUTAMIAS QUADRIVITTATUS:—*Nematodirus sp., Oxyuris sp.*

EVOTOMYS GAPPERI GALEI:—*Anoplocephala sp.*

GEOMYS BURSARIUS. See *G. lutescens.*

GEOMYS LUTESCENA:—*Ceratophyllus ignotus.*

LEPUS CAMPESTRIS:—*Davinea salmoni, Hoplopsyllus sp., Taenia pisiformis.*

LEPUS SP.:—*Ctenocephalus inaequalis, Multiceps serialis.*

LEPUS SYLVATICUS (This should be *Sylvilagus sp.*) *Taenia sp.*

LEPUS TEXIANUS:—*Taenia sp.*

MARMOTA FLAVIVENTER:—*Ceratophyllus sp.*

MICROTUS MORDAX:—*Oxyuris sp.*

MICROTUS PENNSYLVANICUS MODESTUS:—*Anoplocephala sp.*

MUS MUSCULUS:—*Oxyuris obvelata, Spiroptera obtusa.*

NEOTOMA CINEREA RUPICOLA:—Cestode, *Nematodirus sp., Oxyuris sp.*

NEOTOMA CINEREA OROLESTES:—*Ceratophyllus spp., Dermacentor venustus* (?), *Hoplopsyllus sp.*

NEOTOMA FALLAX:—*Ceratophyllus sp.; Cuterebra sp.*

NEOTOMA FLORIDANA BAILEYI:—Cestode, *Oxyuris sp.*

NEOTOMA SP.:—*Ctenopsyllus alpinus.*

OCHOTONA SAXATILIS:—*Ceratophyllus sp., Ixodes angustus* (?).

PEROMYSCUS SP.:—*Anoplocephala sp.*

Rabbit:—Cestode, *Cuterebra cuniculi.*

Rock squirrel. See *Citellus variegatus grammurus.*

SCIURUS ABERTI. See *S. a. ferreus.*

SCIURUS ABERTI FERREUS:—*Ceratophyllus montanus.*

SCIURUS FREMONTI:—*Ceratophyllus coloradensis, Ceratophyllus divisus, Ceratophyllus lucidus.*

SYLVILAGUS AUDUBONI BAILEYI:—*Davinea salmoni, Hoplopsyllus affinis, Hoplopsyllus sp., Spilopsyllus sp., Spiroptera sp., Taenia pisiformis.*

SYLVILAGUS NUTTALI PINETIS:—*Cittotaenia mosaica.*

SYLVILAGUS SP.:—*Multiceps serialis.*

THOMOMYS FOSSOR:—Cestode, *Chabertia sp.*, Nematode, *Trichuris sp.*

THOMOMYS SP.:—Cestode.

THOMOMYS TALPOIDES AGRESTIS:—*Ceratophyllus ignotus.*

Western gray squirrel:—*Haematopinus montanus.*

(4.) *UNGULATA.*

BOS TAURUS:—*Chrysops vittatus, Cooperia oncophora, Coccidium oviforme, Dermacentor reticulatus, Echinococcus granulosus, Fasciola hepatica, Fasciola magna, Filaria cervina, Gongylonema scutatum, Haematobia serrata, Haemonchus contortus, Hypoderma lineata, Neuroryctes hydrophobiae, Œsophagostomum radiatum, Ornithodoros megnini, Osteragia osteragi, Psoroptes communis bovis, Sarcocystis miescheri, Tabanus atratus, Tabanus lincola, Taenia saginata.*

CAPRA HIRCUS ANGORIENSIS:—*Haemonchus contortus, Nematodirus filicollis, Trichodectes limbatus.*

EQUUS CABALLUS:—*Ascaris equorum, Cylichnostomum catina-*

tum, Cyclichnostomum sp., Cylichnostomum tetracanthum, Dermacentor reticulatus, Filaria papillosa, Gastrophilus equi, Gastrophilus haemorrhoidalis, Gastrophilus nasalis, Haematopinus asini, Neuroryctes hydrophobiae, Oxyuris curvula, Strongylus edentatus, Strongylus equinus, Strongylus vulgaris, Trichodectes pilosus.

OVIS ARIES:—*Chabertia ovina, Haematopinus pedalis, Haemonchus contortus, Melophagus ovinus, Moniezia expansa, Moniezia trigonophora, (?) Multiceps multiceps, Nematodirus filicollis, Œstrus ovis, Ostertagia bullosa, Ostertagia circumcincta, Ostertagia marshalli, Ostertagia occidentalis, Psoroptes communis ovis, Sarcocystis tenella, Strongyloides papillosus, Taenia hydatigena, Thysanosoma actinioides, Trichostrongylus sp., Trichuris ovis.*

OVIS CANADENSIS:—*Psoroptes communis ovis.*

SUS SCROFA DOMESTICA:—*Ascaris suum, Demodex folliculorum, Echinorhynchus hirudinaceous, Haematopinus suis, Spiroptera strongylina, Taenia solium.*

(5.) *CHIROPTERA.*

CORYNORHINUS MACROTIS PALLESCENS:—*Trichobius corynorhini.*

MYOTIS EVOTIS:—*Ceratopsyllus crosbyi, Nycteribia sp.*

2. *AVES.*

ACCIPITER VELOX:—*Physaloptera alata.*

ASIO FLAMMEUS:—*Docophorus sp.*

ASIO WILSONIANUS:—*Filaria sp.*

BOTAURUS LENTIGINOSUS:—*Colpocephalum laticeps.*

CENTROCERCUS UROPHASIANUS:—Cestode, *Rhabdometra nullicollis.*

CORVUS CORAX SINUATUS:—*Docophorus distinctus.*

CYANOCITTA STELLERI DIADEMATA:—Cestode.

GALLUS GALLUS:—*Choanotaenia infundibulum, Cnemidocoptes mutans, Coccidum tenellum, Davinea tetragona, Dermanyssus gallinae, Heterakis papillosa, Heterakis perspicillum, Laminosioptes cysticola, Lipeuris docophoroides.*

Menopon biseriatum, Menopon pallidum, Trombidium holoseriseum.

GRUS AMERICANA:—*Colpocephalum assimile.*

JUNCO HYEMALIS OREGONUS:—*Physostomum hastatum.*

Killdeer:—*Haemaphysalis chordeilis.*

MELEAGRIS GALLOPAVO:—*Coccidium tenellum, Metroliasthes lucida.*

Myrtle warbler:—Cestode.

Red-headed woodpecker:—Cestode.

SIALIA SIALIS:—*Docophorus siallii.* (Erroneous record.)

Song sparrow:—*Physostomum sp.*

SPEOTYTO CUNICULARIA HYPOGAEA:—*Docophorus speotyi.*

STERNELLA MAGNA NEGLECTA:—*Aploparakis* (?), *Filaria attenuata.*

Whooping crane. See *Grus americana.*

ZENAIDURA MACRURA CAROLINENSIS:—Cestode.

3. *REPTILIA.*

(1.) *OPHIDIA.*

THAMNOPHIS SP.:—*Haemogregarina sp.*

4. *AMPHIBIA.*

(1.) *URODELA.*

AMBLYSTOMA TIGRINUM:—*Proteocephalus lönnbergi* (?).

(2.) *ANURA.*

BUFO VIRGINIANUS:—*Tropidocerca sp.*

Frog:—Trematode, *Nyctotherus sp., Opalina sp.*

5. *PISCES.*

Sucker:—*Ligula simplicissima.*

Trout:—*Achtheres* or *Lernaeopoda,* Cestode, Trematode.

(II.) ARTHROPODA.

1. *INSECTA.*

APHODIUS COLORADENSIS:—*Macrocheles sp.*

APHODIUS VITTATUS:—*Macrocheles sp.*

CANTHON CHALORTES:—*Pigmeophorus sp..*

ELEODES HISPILABRIS:—*Stylocephalus giganteus.*
ELEODES OBSOLETA:—Nematode.
ELEODES SP.:—*Stylocephalus giganteus.*
Grasshopper:—*Microtrombidium locustarum, Sarcophaga sp..*
MELANOPLUS COLORADENSIS:—*Hirmocystis rigida.*
LISTROCHELUS FIMBRIPES:—*Tyroglyphus sp.*
MELANOPLUS SP:—*Hirmocystis rigida.*
MELOPHAGUS OVINUS:—*Crithidia melophagi.*
Mountain cricket:—Gregarine.
MUSCA DOMESTICA:—*Habronema muscae.*
OSMIA LEONIS:—*Trichotarsus sp.*
PLATYSTETHUS AMERICANUS:—Gregarine.

(III.) ANNULATA.

Earthworm:—*Monocystis sp.*

(IV.) HOSTS NOT GIVEN.

Aedes curriei, Aedes nigromaculis, Aedes sp., Aedes sylvestris, Calliphora viridescens, Calliphora vomitoria, Ceratopogon cockerellii, Ceratopogon specularis, Chrysops carbonarius, Chrysops coloradensis, (?) Chrysops coquilettii, Chrysops discalis, Chrysops fulvaster, Chrysops lupus, Colpocephalum laticeps, Ctenocephalus canis (?), Culex tarsalis, Culiseta incidens, Culiseta inornatus, Culiseta sp., Cuterebra americana, Cuterebra lepivora, Cuterebra lepusculi, Cuterebra tenebrosa, Dermacentor variabilis, Erpobdella punctata, Gordius lincatus, Gordius longareolatus, Gordius spp., Haematopota americana, Iphis sp., Ixodes cookei, Laelaps sp., Mermis sp., Pangonia incisa, Placobdella rugosa, Pulex sciuri (?), Sarcophaga sp., Silvius gigantulus, Simulium fulvum, Tabanus centron, Tabanus coffeatus, Tabanus epistalus, Tabanus insuetus, Tabanus intensivus, Tabanus phaenops, Tabanus punctifer, Tabanus reinwardtii, Tabanus rhombicus, Tabanus septentrionalis, Tabanus sonomensis, Tanypus occidentalis.

IV. SUMMARY.

In this summary the word *identified* is used to indicate that at least a generic indentification has been given. The foregoing list of Colorado parasites includes 15 identified and 2 unidentified protozoan forms, 2 identified and 2 unidentified trematoda, 34 identified and 13 unidentified cestoda, 67 identified and 8 unidentified nemathelminthes, 2 identified annelida, 1 unidentified crustacean, 15 identified platyptera, 7 identified hemiptera, 59 identified and 1 unidentified diptera,, 27 identified siphonaptera, and 27 identified arachnida; a total of 250 identified and 27 unidentified parasites, or 281 altogether. These are recorded from two species of primates, 9 carnivores, 37 rodents, 6 ungulates, and 2 bats (a total of 56 mammalian hosts); from 19 birds (one of the bird records is an error); from 1 reptile; from 3 amphibians; from 2 fish (the total vertebrate hosts being 81); from 15 insects; and from 1 annelid (the total invertebrate hosts being 16). The total vertebrate and invertebrate hosts is 97. Including counties quarantined for sheep and cattle scab, parasites are recorded from 117 localities in 55 counties. There are no records from 7 counties. Of a total of 310 records of all parasites from all places, exclusive of scab in sheep, about one-third of the records are from Colorado Springs and Fort Collins, due to the fact that Dr. Ransom and the writer have been collecting at Colorado Springs, and Dr. Kaupp at Fort Collins.

The following parasitic species were described from Colorado: *Fasciola carnosa* seu *americana* Hassall, 1892 (Found to be identical with *F. magna;* collected in abattoir inspection and has no place as an established parasite in this state); *Cittotaenia mosaica* Hall, 1908; *Ostertagia bullosa* Ransom and Hall, 1912; *Rhabdometra nullicollis* Ransom, 1909; *Docophorus spcotyti* Osborn, 1896; *Physostomum hastatum* Osborn, 1902; *Haematopinus montanus* Osborn, 1896; *Ceratopogon cockerellii* Coquillet, 1901; *Ceratopogon specularis* Coquillet, 1901; *Tanypus*

occidentalis Coquillet, 1902; *Trichobius corynorhini* Cockerell, 1910; *Ceratophyllus coloradensis* (Baker, 1895); *Ceratophyllus divisus* (Baker, 1895); *Ceratophyllus hirsutus* (Baker, 1895); *Ceratophyllus ignotus* (Baker, 1895); *Ceratophyllus lucidus* Baker, 1904; *Ceratophyllus montanus* (Baker, 1895); *Ctenopsyllus alpinus* (Baker, 1895); and *Hoplopsyllus anomalus* (Baker, 1904).

The cooperation of zoologists, physicians, and veterinarians in enlarging this record will be appreciated. Parasites may be sent for identification to the Zoological Division of the Bureau of Animal Industry, or records sent to the writer will be included in a subsequent paper if the number received warrants it.

A valuable host reference will be found either in the work of Warren (1910) or Cary (1911).

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William C. Sturgis, Ph. D.

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A GUIDE TO THE BOTANICAL LITERATURE OF THE MYXOMYCETES FROM 1875 TO 1912.

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The following compilation has arisen out of the writer's necessities in a study of the Myxomycetes extending over the past twenty years. The literature of this subject is so varied in character and is included in publications often of so limited a circulation, that it is well-nigh impossible for the student to ascertain what work has been done along a specific line of research unless he has himself followed and recorded the literature as it appeared or has access to some very complete technical library. Even so, the task of searching out the desired material, especially if it be a specific subject rather than an author which is sought for, is not only laborious but too often fruitless.

The present writer has been fortunate in the possession, for many years, of a fairly good library, and recently in the opportunity of examining the exceptionally complete library of Professor W. G. Farlow of Harvard University. It has therefore been possible to compile a bibliography which is believed to include a majority of the botanical titles issued since the date of Rostafinski's Monograph.

A few words of explanation regarding the form which this compilation has finally taken may serve to render it more readily available.

Inasmuch as Rostafinski's Monograph contains a bibliography, the date of its publication has been taken as a starting-point. No titles previous to 1876 are therefore included in the following list except such as are omitted in Rostafinski's bibliography. It has been thought advisable however, to cross-refer many of the titles listed by that author under the appropriate subject-title. In such cases the fact is indicated by the bracketed letter R following the citation.

Whenever articles cited have been reviewed in current journals, such reviews are also cited, the references thereto being

enclosed in brackets. In many instances it has been possible to add also a brief note referring to the article in question.

It has proved a matter of great difficulty to select suitable subject-headings and the references under such headings. To have adopted a complete cross-reference system including all of the leading words in the titles cited as well as precise references to monographs and works of a general character wherein the various subjects are treated, would manifestly have extended the work beyond all reasonable bounds. The plan adopted will, it is hoped, enable the student to obtain at least a clue to what has been done along the line which he desires to pursue. The compiler has also confined himself fairly closely to citations from botanical authors only. Undoubtedly therefore, much valuable material has been omitted especially in the fields of physiology and cytology.

The rules of citation adopted by the Madison Botanical Congress have been followed in a general way, but no rules can cover all cases.

In order to distinguish readily between subject-headings and citations of authors, the former are printed in heavy-face type. In order to save space, the citations under subject-headings are greatly abbreviated; by referring however, to the corresponding author-heading, the citation will be found in a more complete form.

In conclusion the compiler desires to express his indebtedness to Professor W. G. Farlow of Harvard University for invaluable assistance in the preparation of this bibliography, not only in permitting the free use of his library but also in the labor of verifying many of the references.

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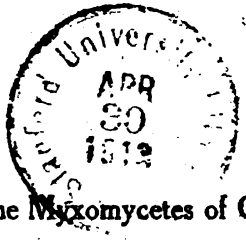

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THE MYXOMYCETES OF COLORADO. II.

By W. C. STURGIS.

The following notes on Colorado Myxomycetes are the result mainly of collecting trips made to various portions of the State during the past two summers. The work is supplementary to my first paper on the subject, published by the Trustees of Colorado College in 1907, as No. 1 of Vol. XII, in the Science Series. Hence, except in a few instances where further notes seemed advisable, the species herein recorded are new to Colorado. The localities which have been fairly thoroughly explored are as follows. They form together only a small fraction of the accessible area of the State, but they are representative of most of the conditions determining the distribution of plant-life in Colorado, except the arid plains.

COLORADO SPRINGS and neighborhood within a radius of five miles, including Pike View and Cheyenne Mt., the former presenting a sandy creek-bottom, with dominant vegetation of *Populus angustifolia* and undergrowth of *Symphoricarpos* and *Clematis ligusticifolia;* alt. 6,000-6,200 ft. Cheyenne Mt., alt. 9,400 ft.; dry, rocky slopes with dominant vegetation of *Pinus spp.* and *Populus tremuloides;* dry or moist ravines with *Picea pungens* and *P. Engelmannii, Populus spp.,* and undergrowth of *Rubus spp., Ribes spp., Rosa spp.,* and *Acer glabrum.*

TOLLAND, Northwest of Denver, on the East slope of the Continental Divide, alt. 9,000 ft.; a very varied region with dry *Pinus* slopes; cold, damp forests of *Pseudotsuga, Picea spp.,* and *Abies lasiocarpa;* and boggy hillsides with dense thickets of *Alnus tenuifolia,* etc. One of the most favorable localities in the State for Myxomycetes.

PAGOSA SPRINGS, Southwestern Colorado, near the New

Mexico boundary, alt. 7,000-7,500 ft.; dry, rocky hills, rising from the narrow valley of the San Juan River. Dominant vegetation, *Pinus spp.*, with scattered growths of *Pseudotsuga, Picea* and *Abies*. River-bottom densely covered with *Populus spp.* and *Alnus;* soil sandy, much shrubby undergrowth.

WET MOUNTAIN VALLEY, Custer Co., West of Pueblo, at the foot of the Sangre de Cristo Range. The forests on the East slopes of the mountains (alt. 7,900-11,000 ft.), afford an excellent field for the collector. *Pinus scopulorum* and *P. flexilis* form the dominant vegation of the lower, drier slopes; creek beds dense with *Populus spp., Acer glabrum* and *Alnus;* at higher elevations dense forest of *Pinus Murrayana, Pseudotsuga, Abies* and *Picea;* intermediate groves of *Populus tremuloides.*

In all of the mountainous localities there is much fallen, decaying timber which affords an excellent substratum for lignicolous Myxomycetes, notably *Stemonitaceae, Physaraceae* and *Cribrariaceae.* On the other hand in the sandy creek-bottoms, with their dense cover of *Symphoricarpos* and *Clematis,* are to be found in abundance such foliicolous species as *Didymium anellus, D. Clavus, D. nigripes, Craterium leucocephalum, Diachaea subsessilis, Perchaena vermicularis,* etc. Wherever the larger species of *Populus* occur, their fallen trunks usually afford fine gatherings of *Badhamia spp., Perichaena depressa, Trichia contorta, Physarum auriscalpium, Lycogala flavo-fuscum,* etc.

CERATIOMYXA PORIOIDES, (*A. & S.*) *Schroet.* This form, common throughout the rest of the United States, has not been hitherto reported from Colorado. In July, 1912, it was found, though not in abundance, in the Wet Mountain Valley. It is worthy of note that, although *C. fruticulosa* was found in great abundance in the same locality, no intermediate forms were seen.

BADHAMIA UTRICULARIS, (*Bull.*) *Berk.* and,

B. MAGNA, *(Pk.)List.* These two forms may properly be considered together, both on account of their extremely close relationship and because of their frequent occurrence together in the same locality. It is rather strange that there should have been heretofore only one record of *B. utricularis* from Colorado, inasmuch as it is apparently not uncommon, growing on the under side of partially supported fallen trunks of *Populus* in damp localities. It was found, in fine condition, on September 24th, in the Wet Mountain Valley. The loosely clustered spores vary in color from pale to bright umber, are less distinctly spinulose than those of European gatherings, and measure 8-11.5 μ in diameter, when spherical. Frequently the spores are oval.

The form known as *B. magna* is much more abundant than the typical *B. utricularis.* During the past two years it has been collected at Pike View near Colorado Springs, at Tolland, and in the Wet Mountain Valley. All of the specimens have been examined with the utmost care and compared with the type of *B. magna* and with authentic material of *B. utricularis* received from the late Mr. Arthur Lister. So far as the form and habit of the sporangia are concerned, the two species present no appreciable differences. The capillitium of *B. magna* has, possibly, a tendency to be less calcareous and rigid than that of *B. utricularis.* It is only in the spores that any difference is discernible, those of *B. utricularis* being usually very loosely clustered and of a pale to bright umber color, while in *B. magna* they are always free and vary in color from dull umber to purplish brown. As a rule too, the spore-markings are coarser in the case of *B. ultricularis,* though the specimens from the Wet Mountain Valley show minutely spinulose spores as in the case of typical *B. magna.* A careful series of measurements shows the dimensions of the spores to be practically the same in both species—*B. utricularius,* 8-11.5 μ.; *B. magna,* 8.5-11.7 μ.

BADHAMIA DECIPIENS, *(Curt.) Berk.* This rare species, hitherto reported, in America, only from the Eastern

States, was found on Cheyenne Mt., in September, 1908, and again in August, 1909. The specimens show some noteworthy divergences from the normal form. They consist of sessile, globose sporangia or short plasmodiocarps, with membranous walls, orange toward the base and paler above. Many of the sporangia are bronze-iridescent from the absence of lime; in other cases they are more or less incrusted with yellow-stained, rugose deposits of lime. The capillitium consists of large, branching, pale-yellow lime-knots with a few connecting threads. The spores are purplish brown, more or less ovoid, minutely spinulose, and measure 8-10 μ. diam. Some years ago I received precisely this same divergent form of *B. decipiens* from Mr. Hugo Bilgram of Philadelphia.

BADHAMIA MACROCARPA, *(Ces.) Rost.* Professor W. G. Farlow of Harvard University has submitted to me a fine gathering of this species made by Mr. E. Bethel of Denver, in February, 1910, on old *Yucca* stems at Leyden, Colo. The crowded sporangia are usually supported on short, pale yellow, membranous stalks. The spores are purplish brown, minutely and more or less evenly spinulose and marked in addition with the peculiar bands or ridges characteristic of the spores of *Badhamia populina;* they measure 12-14 μ. diam.

During the summer of 1912, this species was repeatedly found in the neighborhood of Colorado Springs, growing inconspicuously but abundantly on dead leaves and twigs, in company with various species of *Didymium* and *Physarum*, beneath tangled masses of *Clematis*. If the Leyden specimen be taken as one extreme in the series designated by the name *Badhamia macrocarpa*, these specimens represent the other. The scattered stipitate sporangia, 0.5 mm. in diameter, are turbinate or discoid and plane or concave above; the blackish stalks measure 0.25 mm. in height and somewhat less in thickness; the white lime-knots of the capillitium are large and angular and are connected by short threads; the spores are very dark purplish brown, strongly spinulose on one side, paler and smoother on the other, and measure 12-14.5 μ. diam. Were

it not for the dark spores, these specimens would unquestionably be placed under *Badhamia orbiculata, Rex.* In this connection it is worthy of note that the specimen distributed in Klotzsch, Herb. Viv. Mycol., No. 1968, under the name *Physarum macrocarpon, Ces.,* appears to combine the characters of *Badhamia macrocarpa* and *B. orbiculata,* showing sporangia either sessile or borne on short, stout, dark brown stalks, and a capillitium consisting of stiff, branching tubules with few expansions and scanty lime. The spores however, are dark purple brown, and measure 11-13 μ. diam.

PHYSARUM LEUCOPUS, *Link.* A single scanty gathering of this species was made on Cheyenne Mt., September 10th, 1908. It appears to be decidedly rare.

PHYSARUM LUTEO-ALBUM, *List.* In August, 1911, a most extraordinary species of *Physarum* was found growing on decayed wood in the Wet Mountain Valley. The globose sporangia, bronze-iridescent from the absence of lime, are borne, singly or in pairs, on thick stalks of a spongy texture, densely charged with white lime stained with orange above. Rarely they form plasmodiocarps seated upon a white base. The sporangium wall is membranous and bright yellow or orange. The capillitium, rigid and persistent, is composed of a network of delicate, anastomosing tubules, slightly expanded at the angles, pale yellow in color, and with occasional angular, yellow lime-knots. Some of the sporangia show a small, conical columella. The spores are purplish brown, strongly spinulose, and measure 12-14 μ. diam.

These specimens were so unlike any form of *Physarum* known to me that I submitted them to Miss G. Lister, by whom they were determined as *P. luteo-album.* This is the first record of the species in America. It differs from the European gatherings only in the absence of lime on the sporangia.

PHYSARUM VIRIDE, (*Bull.*) *Pers.* var. BETHELII, *Macbr.* In August, 1908, I collected on Cheyenne Mt., near Colorado Springs, a form of *Physarum* characterized by a

rather robust habit; a peculiar greenish yellow color; large, branching, pale yellow lime-knots, and rather dark, violet-brown, distinctly spinulose spores measuring 8.5-9.8 μ. diam. Specimens were submitted to Miss Lister, who determined them as *P. Bethelii, Macbr.,* a species based on a small gathering made by Mr. Bethel, of Denver, and differing from *P. viride* in the stouter habit, coarser capillitium and somewhat darker spores. Since that time I have made a number of gatherings on Cheyenne Mt. and in the Wet Mt. Valley, which throw doubt on the validity of *P. Bethelii.* Some are bright yellow in color, scattered and delicate, or sessile and aggregated in clusters, with small and fusiform, or rod-like and branching lime-knots, and with rather dark violet-brown spores. In others the sporangia are greenish yellow with rather large lime-knots, but with paler violet-brown spores. Others again, with the darker spores, show small, fusiform lime-knots. In fact the darker spores and the coarser capillitium do not occur together in the same gathering with sufficient frequency, to warrant our considering them as specific characters. *P. Bethelii* appears to bear the same relationship to *P. viride,* as do the stouter varieties of several stipitate species of *Physarum* to the species themselves.

PHYSARUM MAYDIS, (*Morg.*) *Torrend.* The larger lime-knots and the slender, reddish brown, translucent stalks, may serve to distinguish this species from forms of *P. viride,* though the above notes under that species indicate a very close relationship. It also approaches *P. flavicomum, Berk.* more closely than is convenient. An authentic specimen of *P. Maydis,* received from Mr. Morgan, shows rather large, angular lime-knots, clear yellow in color, often with darker centers, and pale, smoky-brown spores, 8-10 μ diam., minutely and irregularly spinulose, the spinules being more or less grouped in clusters. With this, a specimen collected on Cheyenne Mt. in August, 1912, agrees in all essential respects.

PHYSARUM CARNEUM, *List. & Sturgis.* This spe-

cies was described by Miss Lister, (Monograph of the Mycetozoa, p. 63,) from specimens gathered by me on Cheyenne Mt., September 10th, 1908. It has not been found since then. In many of its features it bears a close resemblance to *P. citrinum, Schum.*, and were it not for the complete absence of lime in the stalk, I should have no hesitation in referring it to that species. It is also related to such forms as *P. citrinellum, Pk.* and *Craterium aureum, (Schum.) Rost.*, to the latter especially in the somewhat cartilaginous base of the sporangium wall merging into the translucent, sulcate, golden yellow stalk, (described by Miss Lister as "pinkish flesh-coloured"). For the present *P. carneum* may be retained as a distinct species, but it is more than likely that future gatherings will prove its identity with one of the above-mentioned species.

PHYSARUM BRUNNEOLUM, *(Phill.) Mass.* What appears to be this species occurred in considerable abundance on the dead bark of *Populus* on Mt. Manitou near Colorado Springs, in July, 1912. The gregarious sporangia, or short plasmodiocarps, are dirty white or tawny in color, and the sporangia occasionally show short, dark stalks. The wall is smooth externally, cartilaginous in texture and ruptures either in a circumcissile manner or in revolute lobes, exposing the white, rugose inner surface. The capillitium consists of abundant, large, rounded lime-knots, connected by short threads. The spores are dark purplish brown, coarsely spinulose and measure 10-11 μ. diam.

It may here be noted that a remarkable gathering of this species has been submitted to me by Prof. Thaxter, of Harvard University. The sporangia are very large, measuring as much as 1.5 mm. in diameter, as compared with 0.7 mm. in the specimen noted above; the spores are somewhat larger and paler. This gathering was made at Punta Arenas, Chili, in March, 1906.

PHYSARUM PUSILLUM, *(Burk. & Curt.) List.* This

species is probably common throughout Colorado but has been overlooked owing to its extraordinary resemblance in gross characters to *Didymium nigripes, Fr.* It was found in some abundance at Pike View, Colo., in August, 1912, growing on dead twigs and leaves under tangled masses of *Clematis,* in company with the *var. eximium* of the above-mentioned *Didymium.* The latter was found in such quantity that it was neglected, and it was only later that the presence of the *Physarum* was recognized in the small amount of material saved.

PHYSARUM NUTANS, *Pers.,* subsp. LEUCOPHAEUM, *(Fr.) List.* A typical gathering of this form was made at Pike View in August, 1912, associated with the *Physarum* and *Didymium* above-mentioned. It appears to be fairly common.

PHYSARUM COMPRESSUM, *Alb. & Schw.* In the Wet Mt. Valley in August, 1911, and in August of the following year at Tolland, occurred a species of *Physarum* which, on account of its apparently sessile habit, abundant rounded lime-knots and very dark spores, I was inclined to place under *P. vernum, Somm.* A specimen was submitted to Miss Lister however, and by her determined as *P. compressum.* The sporangia are usually sessile, but occasionally one is found which shows a tendency to form a stalk, though the latter is hardly more than the thickened, tapering base of a turbinate sporangium. The membranous sporangium-wall is purplish toward the base; the capillitium consists of rounded, triangular or polygonal white lime-knots, connected by delicate threads; the spores are dark purplish brown, 9-10 μ. diam.

In a previous publication (Colo. College Publ., Sc. Ser. XII, p. 16) I expressed myself as in favor of following Macbride in adopting Rostafinski's designation *nephroideum* for this species. I am still of this opinion, in case *P. compressum, A. & S.* and *P. connatum (Peck) List.,* are one and the same species, as Macbride, following Rostafinski, concludes. (N. Amer. Slime-Moulds, p. 41). If however, the former

differs from the latter in its more or less compressed sporangia and more rounded lime-knots, it may be convenient to regard these as specific differences. As to the validity of the name first given by Albertini and Schweinitz to the compressed form, it at least represents now a definite thing and hence seems worthy of being retained.

PHYSARUM CONTEXTUM, *Pers.* A peculiar form of this common species was found on Cheyenne Mt. in August, 1912. Externally it presents no differences from the normal form, except that the color is more pronounced, being a clear chrome yellow. This color however, is also seen in the lime-knots, which are bright canary-yellow instead of white. The form seems worthy of record, as emphasizing the relation between this species and *P. alpinum, List.*

PHYSARUM VIRESCENS, *Ditm.* A fine gathering of this species was made at Tolland, Colo., late in August, 1912. It occurred on the bark of fallen *Abies* and is typical in every respect.

FULIGO MEGASPORA, *n.s. Plasmodium? Aethalia pulvinate, 15-40 cm. in diameter, covered with a thick spongy incrustation of lime, white, or yellowish toward the base. Component sporangia convoluted, the walls membranous, brittle, charged throughout with round, white granules of lime 1.5-2 μ. in diameter. Columella wanting. Capillitium rather scanty, consisting of delicate, colorless, anastomosing tubules, empty where they arise from the sporangium-walls, but toward the center expanded in branching lime-knots filled with large, white granules of lime. Spores, when fully mature, spherical or somewhat oval, dark purplish brown, closely and coarsely tuberculate, the tubercles sometimes arranged in irregular lines, 15-20 μ diam.* (Pl. 2, figs. 1-3.)

Hab. on dead bark of Abies and Pinus, and on twigs on the ground. Cheyenne Mt., Colorado Springs, Colo., July, 1911, and August, 1912.

This remarkable species has been collected twice in more

or less the same locality, the first gathering being somewhat immature. It differs from *F. septica* in the uniformly white color of the lime throughout and in the character of the spores. From *F. cinerea* it may be distinguished by the spongy texture of the cortex, the large lime-granules and the very large, dark spores. (Cf. Pl. 2, figs. 3, 4, & 5.)

Some months ago I received from Miss Lister a small fragment of a *Fuligo* collected by Dr. R. E. Fries, of Upsala, at Lake Albert Edward, Kongo, Africa., together with the suggestion that the specimen might be identical with those found in Colorado. The fragment showed large lime-granules and very dark, strongly warted spores, 12.5-17.5 μ diam. Miss Lister's suggestion has recently been confirmed by Dr. Fries who, after comparing his African gathering with a specimen of my *Fuligo megaspora,* writes me that they are identical.

DIDERMA SPUMARIOIDES, *Fr.* This very common species is referred to here on account of a large gathering made in the Wet Mt. Valley in September, 1912, which shows a peculiar feature. The threads of the capillitium frequently show large, fusiform expansions filled with white lime. These lime-knots are much more prominent than in any specimen of *D. globosum* that I have seen.

DIDYMIUM ANOMALUM, *n.s. Plasmodium? Sporangia in the form of very thin, effused, grey plasmodiocarps, 2-10 cm. long, 1 mm. or less in thickness. Wall single, membranous, hyaline or yellowish, with rather scanty deposits of small, stellately crystalline or amorphous lime. Columella none. Capillitium consisting entirely of straight, membranous, tubular columns, extending from the base to the upper wall of the plasmodiocarp, 7-22 μ thick and usually containing small, crystalline masses of lime. Spores bright violet-brown, minutely and irregularly spinulose, 10.5-11.5 μ diam.* (Pl. 2, figs. 6-8.)

Hab. on the inner bark of Populus. Colorado Springs, Colo., July, 1911.

This anomalous form was found in some abundance, un-

accompanied by any other. The plasmodiocarps present the appearance of small smears of grey paint on the clean surface of the bark, the resemblance being heightened by a faint, longitudinal striation of the upper surface. It bears some resemblance to an effused form of *Badhamia orbiculata,* especially in the character of the capillitium; but the crystalline lime-deposits seem to exclude it from that genus. That it is a *Didymium* I have no doubt, and I have thought it well to publish the above description as a matter of record, pending further gatherings of the same or a similar form.

DIDYMIUM CRUSTACEUM, *Fr.* Although not hitherto reported from Colorado, this species appears to be fairly common. It has been found at Colorado Springs, in the Wet Mt. Valley and at Tolland. While usually sessile, the stipitate condition is not uncommon. The species occurs in the same localities as *Mucilago spongiosa,* from which it presents hardly any marks of differentiation except the habit. Specimens are before me which might, with equal propriety, bear either name.

DIDERMA EFFUSUM, (*Schw.*) *Morg.* Although this is a very common species throughout the Eastern States and is reported as far west as Nebraska, it has been found but once in Colorado, and that not abundantly. The specimens were gathered in the Wet Mt. Valley in August, 1911, and are in the form of flattened, separate or gregarious sporangia, resembling *Didymium difforme.*

DIDERMA ASTEROIDES, *List.* A gathering of this species, made on Cheyenne Mt., Colorado Springs, in September, 1908, represents its first recorded occurrence in America. As pointed out by Miss Lister (Mon. Mycet., p. 114), it closely resembles *D. radiatum,* especially the darker forms of that species. The Colorado specimens, which have been authenticated by Miss Lister, show sessile, globose sporangia of a rich chocolate-brown color, usually seated on a thin, white hypothallus.

DIACHAEA SUBSESSILIS, *Peck.* This species ap-

pears to be fairly common throughout Colorado. It has been collected at Pike View near Colorado Springs, in the Wet Mt. Valley and at Tolland. The Pike View specimens are noteworthy in that some of them show a marked approach to *D. splendens,* the spores being dark purplish brown and marked with a coarse network composed of blunt spines. Others from the same locality show the normally paler spores with delicate reticulation. All agree in the globose, bronze-iridescent sporangia, and the conical, or sometimes obsolete, columellae.

DIDYMIUM QUITENSE, *(Pat.) Torrend.* In August, 1912, specimens of a *Didymium* were collected near Colorado Springs which, at first sight, were taken to be *D. difforme.* The scattered, pulvinate, white sporangia, with shell-like outer wall, very fragile and separating easily from the membranous inner wall, seemed characteristic of that species. Closer examination however, showed that these specimens could not be so referred. The small crystals of lime forming the smooth, outer crust are more stellate than is usual in *D. difforme;* the capillitium consists of an abundant network of rather stout, dark threads, frequently dark-beaded, paler and slightly tapering at the extremities, straight or rarely flexuose, and anastomosing freely, thus resembling the capillitium of *D. dubium.* The spores however, are very dark purple-brown, closely and coarsely warted, and measure 12-18 μ diam. Pl. 2, figs. 13 & 14.)

The specimens seem referable only to the species described by Patouillard (Bull. Soc. Myc. Fr. **11**:212, 1895) as *Chondrioderma Quitense* and properly transferred by Torrend to the genus *Didymium.* The latter author writes regarding this species, "Diffère de *D. difforme* par son capillitium plus violacé et ses spores fortement echinulées ou verruqueuses, de 13-15 μ." (Broteria **7**:90, 1908.). Miss Lister (Mon. Mycet., p. 126), describes the spore-sculpture as an imperfect reticulation composed of warts and ridges, but Patouillard (l. c.) merely writes, "Sporis globosis, 13-15 μ diam., atro-violaceis, verrucosis." In my specimens the spores

are so dark that even under an oil-immersion lens and with the best illumination it is very difficult to see the arrangement of the warts. In the absence of means of comparison other than the bare description, I refer my specimens as above.

DIDYMIUM CLAVUS, *(Alb. & Schw.) Rost.* This species in its normal form of disc-shaped, stalked sporangia has been found, since the publication of my previous list of Colorado Myxomycetes, occurring abundantly on dry twigs and leaves under thickets of *Symphoricarpos* and *Clematis*. A strictly plasmodiocarpic form, externally resembling *Badhamia orbiculata,* though more spreading and irregular in shape, was found on bark of *Abies* at Pagosa Springs, in August, 1911.

LEPIDODERMA TIGRINUM, *(Schrad.) Rost.* This species has been found but once in Colorado. It occurred on moss and decayed wood in spruce forest at Tolland, late in August, 1912.

STEMONITIS FERRUGINEA, *Ehr.* In my previous list of Colorado Myxomycetes some doubt was expressed as to whether some of the pale ferruginous-spored forms of *Stemonitis* occurring so frequently throughout the United States and going under the names *S. ferruginea, S. Smithii,* etc., might not in reality be the European species *S. flavogenita, Jahn,* distinguished from *S. ferruginea* by its yellow plasmodium. In July, 1912, several plasmodia of a clear, lemon-yellow color were observed on a fallen pine trunk in the Wet Mt. Valley. Two days later these had matured into clusters of tall, ferruginous sporangia with shiny, black, filiform stalks. They had all the appearance of *"Stemonitis Smithii,"* but the yellow plasmodium was puzzling. Microscopic examination showed the close, firm, small-meshed net, and pale, ferruginous, minutely spinulose spores, 5-6 μ diam., characteristic of S. *ferruginea,* as contrasted with the very delicate surface-net and spores measuring 7.5-9 μ which are the distinctive features of a specimen of *S. flavogenita* sent me by Miss Lister. It appears therefore, that the color of the plasmodium is of minor diag-

nostic value in the case of *S. ferruginea,* and that it is this species that occurs so commonly in this country. *S. flavogenita* has never been reported from America.

COMATRICHA ELEGANS, *(Racib.) List.* It is satisfactory to note that in the second edition of Lister's Monograph this form is transferred to the genus *Comatricha* and given a recognized position. It is not included in Macbride's North American Slime-Moulds and is doubtless rare. I have collected it twice in Colorado—in the Wet Mt. Valley, July 26th, 1912, and on Cheyenne Mt., August 2nd., of the same year. The specimens are typical, though the first gathering is remarkable in showing sporangia with stalks 2.5 mm. in length.

ENERTHENEMA SYNCARPON, *n. s. Plasmodium? Total height 0.6-0.8 mm. Sporangia scattered, globose, stalked, 0.4-0.5 mm. diam., black, capped with the expanded apex of the columella. Stalk black, cylindrical, tapering abruptly where it merges into the columella, 0.25 mm. or less high, 0.05-0.13 mm. thick. Columella straight, slender, slightly tapering, expanding at the apex into a disc, 0.06-0.1 mm. diam. Capillitium radiating from this disc; threads coarse, dark, more or less roughened, sparingly branched below, but giving rise at their extremities to numerous short, irregular branchlets. Spores at first nearly hyaline; at maturity becoming dark smoky brown, united in clusters of 4-8, blunt wedge-shaped, strongly spinulose on the exposed surface, becoming globose when freed, 11-12.5 μ diam.* (Pl. 2, figs. 9-12.)

Hab. on decayed wood of Pinus. Pagosa Springs, Colo., August 30-31, 1911.

As will readily be seen this species is precisely like *Enerthenema papillatum, (Pers.) Rost.,* except in the larger, clustered spores and in a few minor details. One immediately recalls Berkeley & Broome's description of *"Enerthenema elegans, Bowm."* in Ann. and Mag. Nat. Hist., [*Enerthenema Berkelyana, (B. & Br.) Rost.*] In that species the authors stated that the spores were "produced in little heads." After an examination of the type however, Lister wrote (Monog.

Mycet. Ed 1, p. 124), "In what remains of the type of *E. Berkeleyanum, Rost.* no spores of an *Enerthenema* can be detected; the specimen is beset with clusters of brown spores or dividing cells of a parasitic fungus." A specimen of my *E. syncarpon* was recently submitted to Miss Lister and under date of May 22, 1912, she writes, referring to a pencil sketch by Berkeley attached to the original specimen of *E. Berkeleyanum* in the Kew Herbarium, "The spore-clusters Berkeley figures in the best magnified drawing are extremely like those in your specimens; but they were all dispersed in the poor remains of the S. Carolina gathering when we examined it in 1892, and only the spores of a fungus (also clustered) measuring 6-7 μ, remained." Berkeley's note that he saw the clustered spores *in situ* is substantiated by his drawing, a copy of which accompanies Miss Lister's letter referred to, as well as by his published figures (1, c. S. 2, Vol. V, Pl. XI) which show round clusters of spores borne on unmistakable fungus-hyphae. Miss Lister's further testimony regarding the only form of spores associated with the specimen in question at the time she examined it, seems to me to involve the actual character of *E. Berkeleyanum* in so much doubt that it would be unwise to attach that name to the Colorado specimens described above.

The question remains whether the clustered spores are sufficient to separate *E. syncarpon* from *E. papillatum*. The classification of the *Badhamias* presents a somewhat analagous case, but, in addition, the rougher capillitium threads and the larger spores, coarsely and unevenly spinulose, afford further characters by which *E. syncarpon* may be differentiated.

LAMPRODERMA SCINTILLANS, *(Berk. & Br.) Morg.* The very rare occurrence of any species of *Lamproderma* in the mountainous districts of Colorado, is quite unaccountable, especially in view of the fact that many species of *Stemonitis* and *Comatricha* are found in abundance. Scanty gatherings of *L. scintillans* were made twice in August, 1912, at Pike View near Colorado Springs, and once in the same

month at Tolland; a few sporangia were also collected on Cheyenne Mt., in August, 1908.

CRIBRARIA PYRIFORMIS, *Schrad.* It is satisfactory to find this species, which is not uncommon in the Eastern States, occurring in Colorado. Its dark color and the large plasmodic granules imbedded in the cup and in the prominent nodes of the net, distinguish it from *C. **aurantiaca*** on the one hand and from *C. **intricata*** on the other. It was found in the Wet Mt. Valley in July and August, 1912. Both gatherings were of the form *notabilis, Rex.*

LICEA FLEXUOSA, *Pers.* This rare species has been found but once in Colorado, and then in very small quantity. A few sporangia were found August 8th, 1912, growing on decayed coniferous wood on Cheyenne Mt.

TRICHIA CONTORTA, *(Ditm.) Rost.* Although *"Trichia inconspicua, Rost,"* is one of the most common of Myxomycetes in Colorado, *T. contorta* has been found but once. This fact adds force to Macbride's contention that the two are distinct species. However, they resemble each other so closely, except for the more irregular spirals on the elaters of *T. contorta,* that I prefer to follow Lister in regarding the form *inconspicua* as merely a well-marked variety. The form *"genuina,"* with very long elaters, marked with irregular, prominent spiral bands, was found on the inner bark of *Populus* at Tolland late in August, 1912.

TRICHIA BOTRYTIS, *Pers.* All of the gatherings made of this species in Colorado are of the ***var. munda,*** with rarely clustered sporangia of a dull yellowish brown color usually marked with paler lines of dehiscence, and elaters with neat, close spiral bands. Wet Mt. Valley, August, 1911; Tolland, August, 1912.

HEMITRICHIA VESPARIUM, *(Batsch) Macbr.* Though very common elsewhere in the United States, this species has been found but once in Colorado. A somewhat

scanty and weathered gathering was made in the Wet Mt. Valley in September, 1912.

HEMITRICHIA ABIETINA, *(Wig.) List.* What I can not but regard as a noteworthy form of this species occurred at Tolland, August 30th, 1912. The capillitium is marked with very prominent rings irregularly dispersed and usually set at right angles to the thread; only occasionally does such a ring, set obliquely and connecting groups of parallel rings, give any indication of a spiral arrangement.

HEMITRICHIA KARSTENII, *(Rost.) List.* Macbride (N. Amer. Slime-Moulds, p. 202) writes concerning this species, "To be looked for north and west." The prophecy is correct, as the form in question appears to be not uncommon in Colorado. I have found it on three occasions—in the Wet Mt. Valley, August 18th, 1911, and again in August, 1912, and at Tolland, August 30th, 1912. The sporangia resemble those of *Trichia contorta* and, like that species, occur on the bark of *Populus*. In my specimens the capillitium forms a loose network of dull, yellow threads, irregular in outline and marked with four or five irregular spirals and small, scattered, spinous processes.

HEMITRICHIA SERPULA, *(Scop.) Rost.* Fine specimens of this species were gathered in the Wet Mt. Valley in August, 1911. Macbride states that the plasmodium is yellow, but, as I observed it, it was milk-white.

ARCYRIA FERRUGINEA, *Sauter.* So striking a species as this would hardly have been overlooked were it not rare. Macbride reports it from Maine and New York only. Lister, for the United States, adds Massachusetts, South Carolina and Washington. In Colorado I have found it only once, and that in small quantity growing on a charred log on Cheyenne Mt., August 21st. 1912.

PERICHAENA VERMICULARIS, *(Schw.) Rost.* This minute species occurs commonly in the neighborhood of Colorado Springs. Gatherings have been made repeatedly at Pike

View where it is found growing on dead twigs beneath tangles of *Clematis,* in company with various species of *Physarum Didymium* and *Comatricha.*

My previous paper on the Myxomycetes of Colorado included 94 species and described two new varieties. Naturally, the species thus reported were, for the greater part, new to the Rocky Mt. region since, previous to 1903, the few species reported were the result of chance gatherings by collectors who had no special interest in this group of organisms. Up to 1907 I had the invaluable assistance of Mr. Ellsworth Bethel, of Denver, an able and tireless collector, thoroughly acquainted with all parts of Colorado. Since that date I have been obliged to do all of the collecting myself in the intervals left by more important duties.

The present list includes 39 species, of which 33 are now reported for the first time from Colorado. Of the latter, three are new to America and three are hitherto undescribed species. We thus have 127 species of Myxomycetes known to occur in Colorado at an altitude of not less than 5000 feet; and since this State is topographically and climatically representative of the whole Rocky Mt. area, the list affords a fair criterion of the richness of this region of high altitudes and rapid changes of temperature, so far as these organisms are concerned. As a rule the more ubiquitous species retain even their minute characteristics remarkably well, even under the trying conditions to which their development is subjected. Abnormal forms are rare. Many species too, formerly supposed to be limited to much lower altitudes, prove to be abundant throughout Colorado. Most interesting examples of the adaptibility and the permanency of distinctive features in the case of the Myxomycetes, are seen in some of these Colorado gatherings; as, for example, *Didymium Quitense,* hitherto reported only from Ecuador, and *Fuligo megaspora* which proves to be identical with a form known only by specimens collected in the Kongo region of Africa.

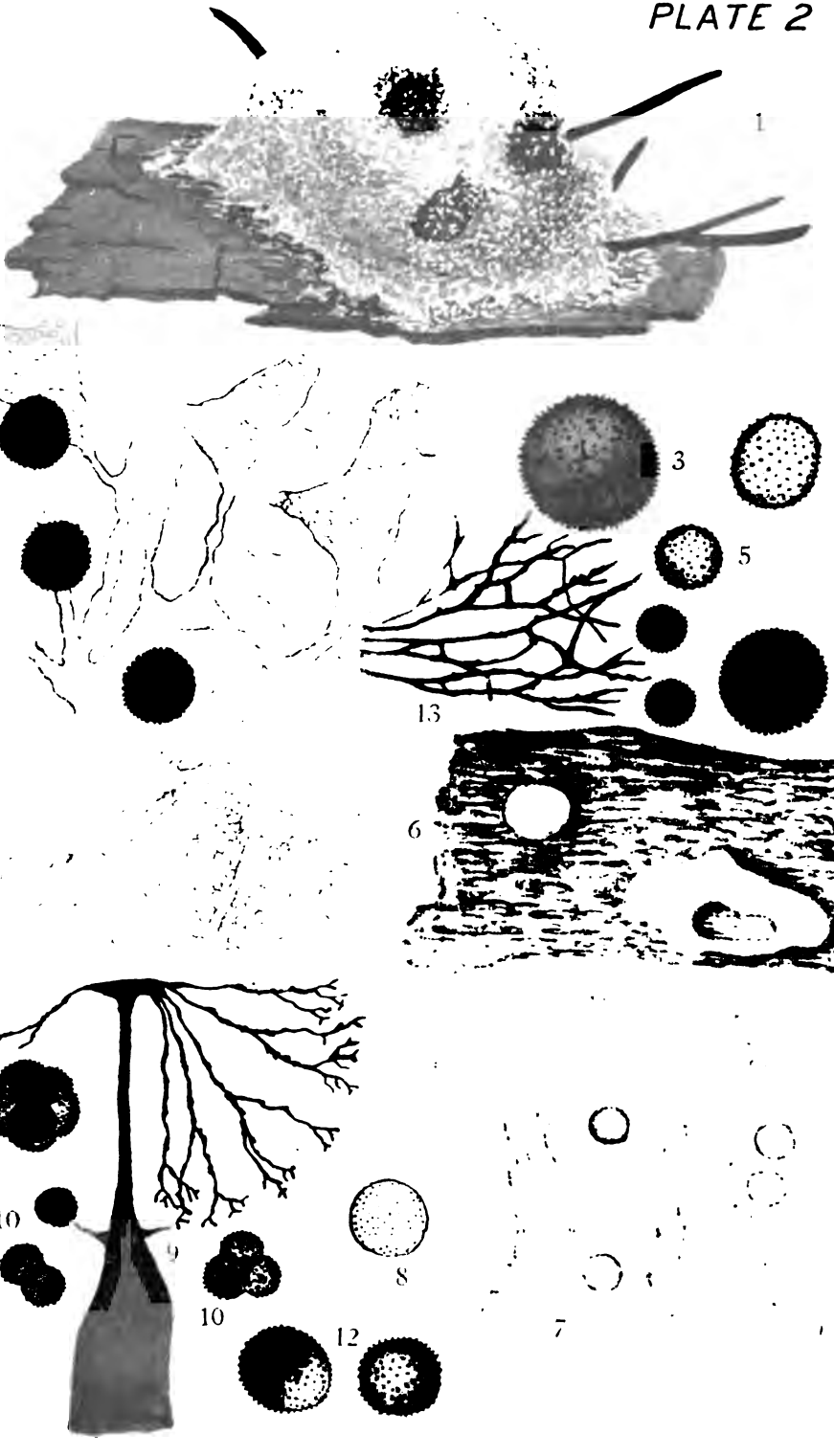
The new varieties described in my previous paper are *Didymium squamulosum, Fr.* var. *claviforme, and Mucilago spongiosa, (Leysser) Morg.,* var. *solida.*

The new species described in the present paper are *Fuligo megaspora, Didymium anomalum,* and *Enerthenema syncarpon.* In addition to these, *Physarum luteo-album, List., Diderma asteroides, List.,* and *Didymium Quitense, (Pat.) Torrend,* are here reported for the first time from America.

Explanation of Plate.

Fig. 1. *Fuligo megaspora, n.s.*, natural size.
Fig. 2. The same. Capillitium and spores. x 475.
Fig. 3. The same. Single spore. x 990.
Fig. 4. Spore of *Fuligo cinerea, (Schw.) Morg.* x 990.
Fig. 5. Spore of *Fuligo septica, (L.) Gmel.* x 990.
Fig. 6. *Didymium anomalum, n.s.*, x 4.
Fig. 7. The same. Columnar capillitium, sporangium-wall and spores. x 475.
Fig. 8. The same. Single spore. x 990.
Fig. 9. *Enerthenema syncarpon, n.s.* x 100.
Fig. 10. The same. Portions of spore-clusters. x 475.
Fig. 11. The same. Spore-cluster of eight spores. x 475.
Fig. 12. The same. Two spores—that on the left, drawn immediately after the forcible dissolution of the cluster; that on the right, still later. x 900.
Fig. 13. *Didymium Quitense (Pat.) Torr.* Capillitium and two spores of a specimen collected near Colorado Springs, August, 1912. x 475.
Fig. 14. The same. Single spore. x 990.

PLATE 2



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Charles E. H. Aiken
and
Edward R. Warren

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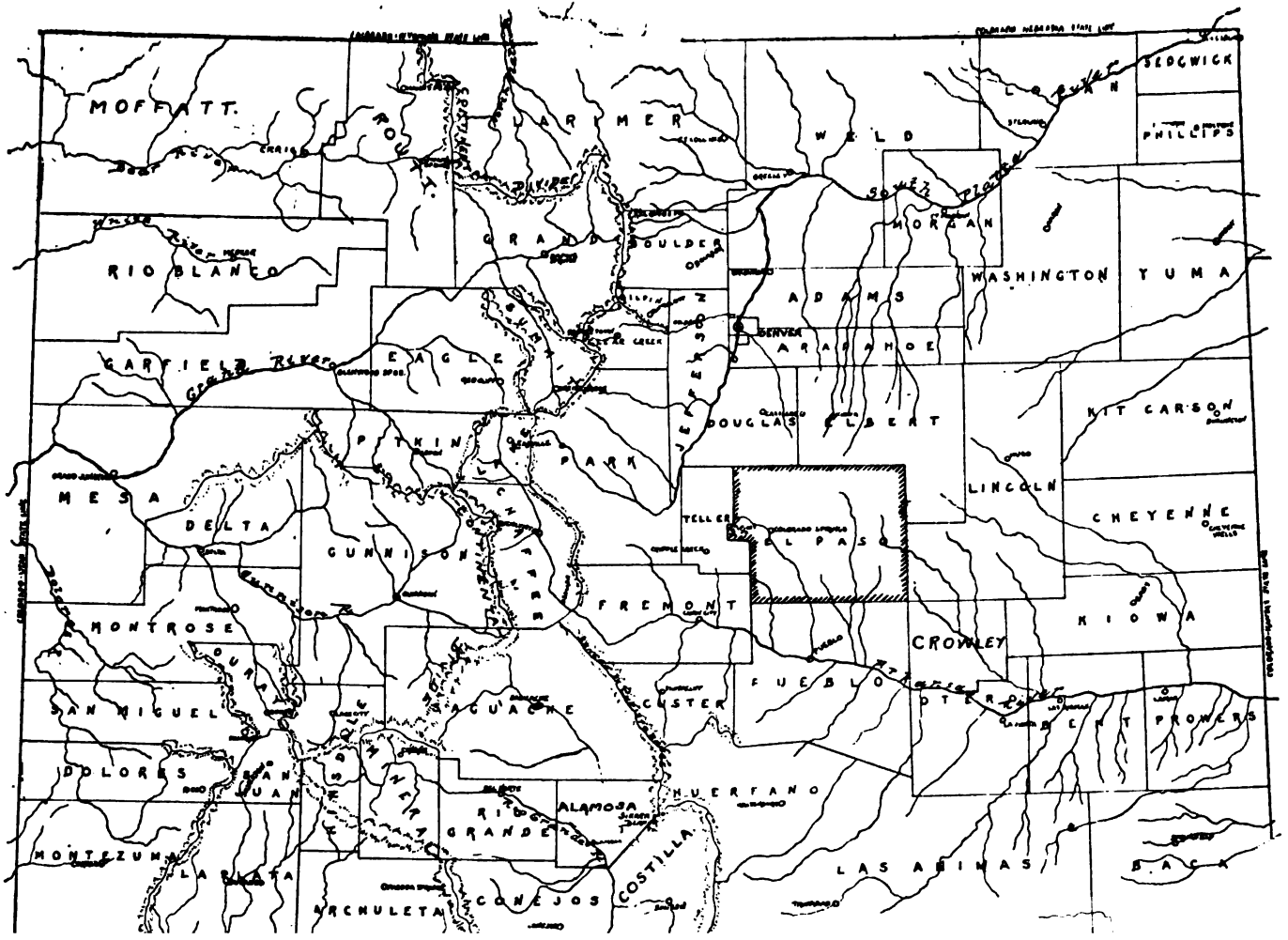

Map of Colorado — Showing Location of El Paso County

The Birds of El Paso County Colorado

By
CHARLES E. H. AIKEN
and
EDWARD R. WARREN
Director of the Museum, Colorado College

PART I

THE BIRDS OF EL PASO COUNTY, COLORADO

AREA INCLUDED IN THIS LIST.

The area covered by this list is the whole of El Paso County, while various notes are given for points without the boundaries of the County, but adjacent thereto, especially that portion of the Pikes Peak Region in which are situated the Seven Lakes.

TOPOGRAPHY.

More than two-thirds of El Paso County is a rolling prairie country, most of the eastern portion of which is dry, with few or no permanent streams, though there are water-courses in which water is found at times, and various springs. The exceptions to this statement are Fountain and Monument Creeks, the former heading in the mountains above Ute Pass, and the latter on the Divide at Palmer Lake and in the foothills west of there, and emptying into the Fountain at Colorado Springs. These streams flow in a somewhat southeasterly course along the east base of the foothills. As shown on the map, the Fountain also receives other tributaries from the west, which have their sources in the mountains.

The extreme western portion of the County is mountainous, occupied by the Pikes Peak Range, which culminates in the well known Pikes Peak, once the objective point of the gold seekers of 1859, now that of the tourists of the twentieth century, who may reach its summit, over 14,000 feet above sea level, by rail. Part of this range is in El Paso County, and part in Teller County, and the boundary lines between the two counties were so drawn that it is difficult to write of that portion of our area without, at times, including a part of Teller County.

This mountain region is rugged, and includes besides Pikes Peak, a number of summits ranging from 11,000 to

above 12,000 feet elevation, and its eastern portion is cut by cañons, many of which are renowned for their beauty or grandeur, such as the Ute Pass, Williams Cañon, Bear Creek Cañon, and North and South Cheyenne Cañons. Ute Pass is the outlet through the mountains by which the Fountain, once called La Fontaine Qui Bouille by the old French trappers, reaches the plains. The trappers called the stream by this name because of the bubbling mineral springs where Manitou is now, and the pass was so named because it was the highway by which the Ute Indians reached the plains. Streams are found in all these various cañons, and high in the mountains about Pike's Peak are Lake Moraine and the Seven Lakes, converted into reservoirs which belong to the water supply system of Colorado Springs.

Standing somewhat apart from the rest, at the southeasterly end of the range, is Cheyenne Mountain, rising abruptly from the plains, and though not lofty, but little over 9,000 feet, it is one of the most beautiful mountains we have, many consider it the most beautiful.

Once the mountains were entirely covered with forest, of pine, spruce, and aspen, but forest fires, some of them many years ago, and some of them of quite recent date, have destroyed considerable of this.

The extreme southwestern portion of the County is a somewhat rolling region, with yellow pines, cedars, and piñons.

The northerly edge of the County is occupied by the "Divide" region, the watershed between the Arkansas and Platte Rivers. This has at Palmer Lake an elevation of 7,200 feet, and the summit of the watershed has an easterly trend. It has an undulating surface, and where not cleared is largely covered by a forest of yellow pines.

About five miles north of Colorado Springs are what are known as the Bluffs, a range of low sandstone ridges presenting sufficient vertical faces which, though low, enough to justify the name. These extend easterly from the foothills for about eight miles out into the plains. They have a few

yellow pines and cedars growing on them, and considerable scrub oak and other shrubbery, and are good resorts for birds.

The westerly part of the County forms part of the Pike National Forest.

LIFE ZONES.

Owing to its varied topography we have within the boundaries of El Paso County no less than five life zones, as follows:

Upper Sonoran, Transition, Canadian, Hudsonian, and Arctic-Alpine; the first named comprising the plains region and the very lowest foothills; the Transition the foothills and the lower portions of the mountains, and the other three are wholly mountain zones. Each of these zones is more or less well characterized by the presence of certain plants and animals which are either peculiar to or largely confined to it.

UPPER SONORAN ZONE.

This zone, which is agriculturally the most important in the County, as noted above covers the plains region. The elevation of its upper boundary varies from a little over 6,000 to nearly 7,000 feet, depending on the steepness and exposures of the slopes in the foohills, the limit naturally being higher on slopes having a southern exposure than on those with a northern. The piñons and cedars, which are usually considered as belonging to this zone, range even higher at times, but such occasions are really overlappings into the Transition. There are comparatively few of these trees in the County.

In El Paso County the following mammals are confined to this zone:

Bailey's Wood Rat, *Neotoma f. baileyi,* Pale Grasshopper Mouse, *Onychomys l. pallescens,* Yellow Pocket Gopher, *Geomys lutescens,* Kangaroo Rat, *Perodipus m. richardsoni,* Baird's and Plains Pocket Mice, *Perognathus flavus* and *P. flavescens,* Black-tailed Jack Rabbit, *Lepus c. melanotis,* Bailey's Cottontail, *Sylvilagus a. baileyi,* and possibly a few others.

The following birds are practically restricted to the zone in the breeding season:

Woodhouse's Jay, Bullock's Oriole, Cañon Towhee, Western Blue Grosbeak, Lazuli Bunting, Long-tailed Chat, Western Mockingbird, Catbird, Brown Thrasher, Baird's Wren, and Western Gnatcatcher. The following species breed especially in the cedar and piñon trees: Ash-throated Flycatcher, Piñon Jay, Black-throated Gray Warbler, Gray Titmouse, and Lead-colored Bush-Tit.

The following trees and shrubs are characteristic of the Upper Sonoran Zone:

Piñon Pine, *Pinus edulis,* two species of cedar, *Juniperus scopulorum* and *J, monosperma,* Broad-leaved Cottonwood, *Populus occidentalis,* Peach-leaf or Almond-leaf Willow, *Salix amygdaloides,* Gray Saltbush or Bushy Atriplex, *A. canescens,* Western Clematis, *C. ligusticifolia,* Flowering Currant, *Ribes longifolium,* Wild Plum, *Prunus americana,* while six species of scrub oaks are found in this and the lower part of the Transition Zone.

TRANSITION ZONE.

The Transition Zone covers the greater portion of the foothills and the lower parts of the mountains proper, and the Divide region in the northern portion of the County. The former are naturally more or less rough, and the latter is an undulating country. The upper limit of the Transition in El Paso County varies from 8,000 to 9,000 feet, changing with the slope exposures. The cedars and piñons seemingly overlap into this zone from the zone below, and there are some places where it is difficult to decide to which zone that locality belongs.

In this County there is but one mammal which can be said to be restricted to this zone, the Northern Tuft-eared or Plain-backed Squirrel, *Sciurus aberti ferreus,* though the Plains or Coues's Pocket Gopher, *Thomomys clusius,* Estes

Park Cliff Mouse, *Peromyscus nasutus,* and Gale's Wood Rat, *Neotoma m. fallax,* are quite characteristic of it. Other species range into it from the zones above and below.

The following birds are quite characteristic of this zone in the breeding season:

Sharp-shinned Hawk, White-throated Swift, Wright's Flycatcher, Long-crested Jay, Mountain Towhee, Green-tailed Towhee, Plumbeous Vireo, MacGillivray's Warbler, Rocky Mountain Nuthatch, Pgymy Nuthatch, Chestnut-backed Bluebird.

The following trees and shrubs are characteristic of this zone:

Yellow Pine, *P. scopulorum,* Red or Douglas's Fir, *Pseudotsuga mucronata,* Willow, *S. irrorata,* Rocky Mountain Birch, *Betula fontinalis,* Alder, *Alnus tenuifolia,* Beaked Hazel-nut, *Corylus rostrata,* one species of Gooseberry, *Ribes ieptanthum,* two species of Ninebark, *Physocarpus intermedius* and *P. monygnus,* Meadow Sweet, *Holodiscus dumosa* and *H. australis,* and Rocky Mountain Maple, *Acer glabrum.*

CANADIAN ZONE.

The Canadian and the two following zones are strictly mountain regions, this one covering the ground from the upper limits of the Transition to between 10,000 and 11,000 feet, and is the most extensive in area of the three Boreal zones. It may be characterized as normally a well forested zone, though none of the trees are exclusively confined to it.

In El Paso County no species of mammal appears to be confined to the Canadian Zone, though there are a number common to it and the Hudsonian, to say nothing of others which are also found in the Transition. The following mammals are characteristic of the two lower Boreal zones:

Fremont's Squirrel, *S. fremonti,* Woodchuck, *Marmota* sp., Colorado or Rocky Mountain Red-backed Mouse, *Evotomys g. galei,* Colorado or Mountain Pocket Gopher, *Thomo-*

mys fossor, Western Red Fox, *Vulpes macrourus,* Shrews, *Sorex v. dobsoni, S. personatus,* and *S. obscurus,* and Water Shrew, *Neosorex navigator.*

The following birds have their center of abundance in the breeding season in the Canadian Zone:

Dusky Grouse, Alpine Three-toed Woodpecker, Red-naped Sapsucker, Williamson's Sapsucker, Olive-sided Flycatcher, Cassin's Finch, Crossbill, Gray-headed Junco, Audubon's Warbler, Red-breasted Nuthatch, Ruby-crowned Kinglet, Townsend's Solitaire, and Audubon's Hermit Thrush.

Though found also in the Hudsonian the heaviest portions of the forests of Limber or Rocky Mountain White Pine, *Pinus flexilis,* and Engelmann's Spruce, *Picea engelmanni,* are in the Canadian Zone. The Aspen, *Populus tremuloides,* has its center of abundance in the Canadian and ranges but little above it. The following willows are common to it and the Hudsonian: Nuttall's or Black Willow, *S. nuttalli.* Bog Willow, *S. glaucops,* and Green-leaved Willow, *S. chlorophylla.*

HUDSONIAN ZONE.

This is the zone immediately below timberline, above the Canadian; it is intermediate in character between that and the Arctic-Alpine Zone, not having any very strongly marked characters of its own, but in its lower limits having much in common with the Canadian, and in the upper portions sharing some of the characteristics of the Arctic-Alpine. Its upper limit varies in altitude from 11,500 to 12,500 feet.

As stated above under the Canadian Zone, a number of species of mammals are common to these two zones, or rather characteristic of the two together. Of these the Woodchuck is more abundant toward timberline, and ranges into the zone above, and two additional species, the Cony, *Ochotona saxatilis,* and Mountain Sheep, are more especially characteristic of this and the zone above, the former being found, in the Pike's Peak Region, mostly from a little below timberline up to the summits of the mountains.

Map of El Paso County, Colorado

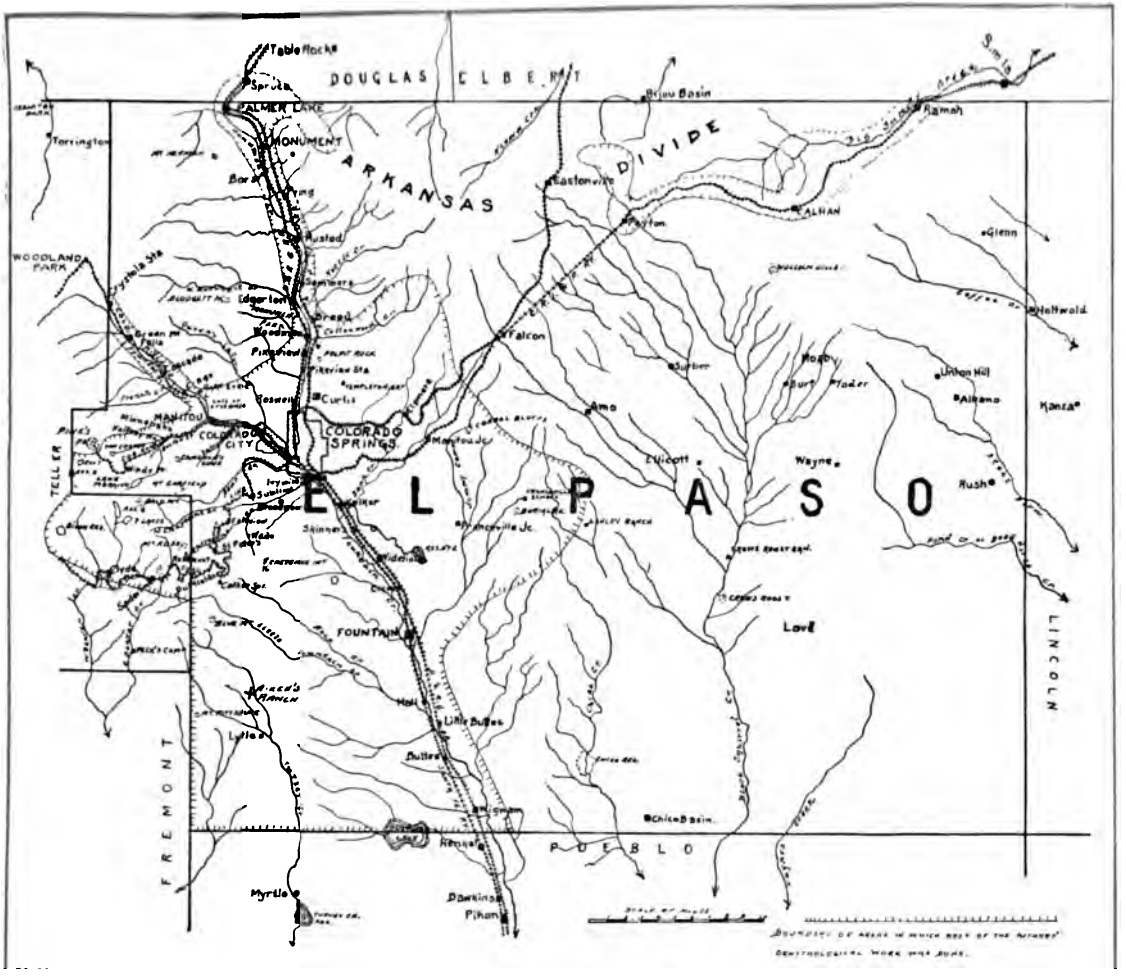

Plate I.

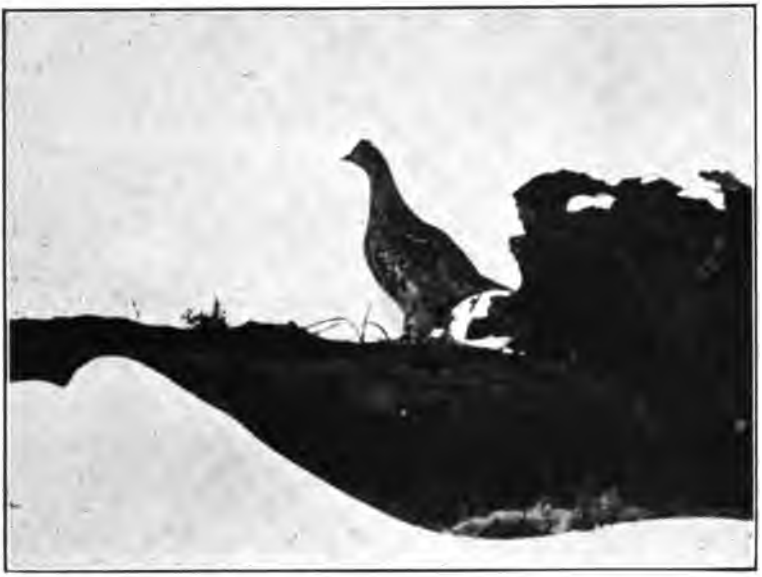

Fig. 1. *E. R. Warren, Photo.*
DUSKY GROUSE.
Gunnison County, Colo.

Fig. 2. *L. L. Shaw. Photo.*
YOUNG SHARP-SHINNED HAWKS, A FEW DAYS OLD.
Crystal Park, Colo.

Fig. 3. *E. R. W., Photo.*
YOUNG SHARP-SHINNED HAWKS, ABOUT THREE WEEKS OLD.

Fig. 4. *L. L. Shaw, Photo.*
YOUNG SHARP-SHINNED HAWKS, ABOUT FOUR WEEKS OLD.
Crystal Park.

Of birds, the Rocky Mountain Jay, Rocky Mountain Pine Grosbeak, and Rocky Mountain Creeper probably breed principally within the limits of the Hudsonian, though there are a number of other breeders in common with other zones.

The only tree which seems to be confined to the Hudsonian is the Foxtail Pine, *Pinus aristata,* which grows from 10,250 feet up to timberline. This zone also includes the upper portions of the Engelmann's Spruce and White Pine forests, and in it are also found the willows mentioned under the Canadian as common to both.

ARCTIC-ALPINE ZONE.

The Arctic-Alpine Zone is the region above timberline, characterized by slopes devoid of trees and with but four species of woody plants growing thereon, though a number of flowering plants are characteristic of it, or nearly so.

No species of mammals is restricted to this zone, but it shares a number of species with the zone below, some of which live here the year round, and others, like the Mountain Sheep, Fox, Coyote, and Black Bear, range into it from below. Some of the species living in this zone the year round are the Woodchuck, Cony, Rocky Mountain Field Mouse, and Colorado Pocket Gopher.

One species of bird is restricted to this zone in the breeding season, the Brown-capped Rosy Finch, and the Pipit is practically so, and the Desert Horned Lark also breeds in the bare spaces, while the White-crowned Sparrow and Pileolated Warbler breed in the willow thickets for five hundred feet above timberline. The Sparrow has been known elsewhere in the State to raise a brood at a lower elevation early in the season, and then to move above timberline and raise a second family, but we have no information as to whether it does this here. A few other birds range intermittently above timberline.

But four species of woody plants grow above timberline, the Dwarf Willow, *Salix saximontana,* and another willow, *S.*

brachycarpa, which are found from 9,000 up to 14,000 feet, Shrubby Cinquefoil, *Dasiphora fruticosa,* 6,500 to 12,400 feet, and the White Mountain Avens, *Dryas octopetala,* 11,500 to 14,000 feet.

The following plants are characteristic of this zone: Catchfly or Campion, *Silene acaulis,* three species of Saxifrage, *Saxifraga debilis, austromontana,* and *rhomboidea,* Stonecrop, *Sedum integrifolium,* Alpine Mertensia, *Mertensia alpina,* Forgetmenot, *Myosotis alpestris,* Lousewort, *Pedicularis parryi,* Polemonium, *Polemonium confertum,* Knotweed, *Polygonum viviparum,* Gentian, *Swertia palustris,* Mountain Avens, *Sieversia turbinata,* Phlox, *Phlox condensata,* Figwort, *Synthyris alpina,* Clover, *Trifolium nanum,* Colorado Candytuft, *Thlaspi coloradense.*

CLIMATE.

In general the climate of El Paso County may be described as temperate, usually without great extremes of heat or cold. though the thermometer does on rare occasions in summer go above ninety in the shade, and similarly in winter fall to thirty below zero. But usually the temperatures are moderate. and neither of the extremes are so hard to bear as in many other places. The plains region has the higher temperature in summer, while there is no great difference in the minimum winter temperatures over the whole county, though the daily mean temperature is greater on the plains than in the mountains.

The rainfall is greatest in the mountains, and least on the plains toward the eastern edge of the County. The winter snowfall is light, comparatively so in the mountains, where it is probably not more than half that on the Continental Divide and the other ranges to the west of us. The snowstorm early in December, 1913, when about two feet of snow fell in Colorado Springs and much more in the mountains, was a very exceptional storm, the like of which had not been known for more than thirty years, and as a rule the deepest snowfalls are in spring, when the snow does not last long.

The number of hours of sunshine are unusually great, a day when the sun does not shine at all being extremely rare. The heavy rain and hail storms which occasionally occur during the breeding season are sometimes destructive to nesting birds, their eggs and young, and a late cold storm in the spring sometimes does much harm to migrants and late arrivals of summer birds. In winter an unusually heavy snowfall may prevent seed-eating birds from obtaining food for a short time, but the snow rarely lays on the ground more than a few days.

As a whole the climate of the County may be described as favorable to bird life.

WORKERS IN THE REGION.

The first ornithologist to visit El Paso County was Dr. J. A. Allen, who came here with an expedition sent out by the Museum of Comparative Zoology, Harvard College, early in August, 1871, and collected along the east base of the foothills from Palmer Lake to Colorado City. His report was published in July, 1872, the first list of Colorado birds.

C. E. Aiken, the senior author of the present paper, came to Colorado Springs, October 26, 1871, not long after the founding of the town, and thenceforward spent much time in collecting in the vicinity, his work for the first two years being nearly all done at his ranch on Turkey Creek, fifteen miles southwesterly from Colorado Springs. The first results of his work were edited by Dr. T. M. Brewer and published in the Proceedings of the Boston Society of Natural History, December, 1872.

H. D. Minot of Boston spent some time in the County in the summer of 1879, and the results of his observations were published in the Bulletin of the Nuttall Ornithological Club.

In March, April, and May, 1882, Dr. J. A. Allen and William Brewster were in Colorado Springs, and did much collecting in the vicinity, publishing their list in 1883, Bulletin of the Nuttall Ornithological Club. Bendire's Thrasher and

the Florida Gallinule were added to the list of Colorado Birds by these distinguished ornithologists.

W. C. Ferrill and Horace G. Smith did a certain amount of collecting in the County while doing work for the State Historical and Natural History Society, making some additions to our list.

E. R. Warren, the junior author of this paper, came to Colorado Springs the fall of 1881, but did no bird work until the next winter, and then did considerable collecting during the winters of 1882-83 and 1883-84. This was dropped for several years, partly owing to absence from the city, and not taken up again here until some dozen or so years ago, since which time he has been making observations and collecting somewhat steadily.

William Lutley Sclater came to Colorado Springs in the autumn of 1906 to take the position of Director of the Museum of Colorado College, retaining this office until the spring of 1909, and spending most of the College year in Colorado Springs, but his summers at his home in England. Though Mr. Sclater did but little field work while here, it was through his influence that the Aiken Collection of Birds was purchased for Colorado College, and it was during his residence here that "The History of the Birds of Colorado" was written, a work which, though by one who had been in the state but comparatively little, shows a great comprehension of the avifauna of Colorado, and represents a great amount of labor on his part in not only going over all the specimens at his command, but also in looking up all the records and literature bearing on the subject. Colorado bird students owe Mr. Sclater a debt of gratitude for the excellent work he has done.

A number of others have made brief stays in the region and published popular articles or books on our birds, while there are some local observers, who, while taking much interest in observing our birds, have published little or nothing about them.

SURVEY OF BIRD LIFE.

The bird life of El Paso County is of a very varied character, nearly all the groups of birds found in the State being represented, while the number of species is a goodly one, 276 all told. The fact that within our limits all the life zones of the State are represented has naturally much to do with this.

That the various species of water birds are not specially abundant is due to the lack of suitable localities to attract them, and any increase in the number of artificial reservoirs along the base of the mountains or on the plains will surely be followed by an increase in the number of waterfowl coming to the region and stopping for a short time at least.

Among the grouse we note the absence of the Ptarmigan. of whose occurrence in the County there is no authentic record. This is due to the fact that the Pike's Peak Range is an isolated one, not connected with the other high ranges of the State, or rather not by any mountains sufficiently high to afford a continuous habitat for this Alpine bird, and moreover the area in the Pike's Peak Range which would be attractive to it is very limited, so that it is not strange it has not gained a foothold here.

Two of our Gallinaceous birds have been exterminated within the last forty years, the Sharp-tailed Grouse and Wild Turkey.

Birds of prey are well represented, both in species and individuals, and the type locality of one subspecies, Aiken's Screech Owl, is within the limits of the County. The Woodpeckers have a good number of species. The Poor-will and Nighthawk and one or more Hummingbirds are common. Flycatchers of various species are numerous, the Magpie and several jays are noticeable, and the *Icteridæ* are represented by blackbirds, the Meadowlark, and Bullock's Oriole.

Sparrows of course show many species, a tanager is common, about all the swallows of temperate North America are here, and a couple of vireos. The list of Warblers is fairly

long, we have the Pipit, Water Ousel, and several of the *Mimidæ*, wrens, nuthatches, several of the *Paridæ*, two kinglets, a gnatcatcher, Solitaire, several thrushes, Robin, and three bluebirds.

This brief résumé shows what a field for bird study the County affords. It has given several original records to the Colorado list, and a considerable number of the rarer species have been reported from here.

ANALYSIS OF THE BIRD FAUNA.

We have divided the birds of the County into the eight following categories, the first six of which are identical with those of Sclater in his History of the Birds of Colorado.

A—Resident throughout the year.

B—Summer residents, migrating south in winter.

C—Birds which breed within the County, and occasionally winter, though usually going further south.

D—Birds not known to breed within the County, but found more or less commonly in winter.

E—Birds not known to breed within the County, but more or less regular transients through in spring and autumn.

F—Birds not known to breed in the County, which have been taken or seen on from one to half a dozen occasions.

G—Species which formerly occurred in the County but now exterminated or not seen for many years.

H—Introduced species.

It is not always easy to determine in which category some of the species should be placed, but we believe the following lists are as near correct as they can be made with the information at hand.

A—Resident throughout the year, 46 species. Virginia Rail, Scaled Quail, Dusky Grouse, Ferruginous Roughleg, Golden Eagle, Long-eared Owl, Aiken's Screech Owl, Western Horned Owl, Acadian Owl, Rocky Mountain Pygmy Owl,

Road Runner, Rocky Mountain Hairy Woodpecker, Batchelder's Woodpecker, Alpine Three-toed Woodpecker, Red-shafted Flicker, Desert Horned Lark, Magpie, Long-crested Jay, Woodhouse's Jay, Rocky Mountain Jay, Raven, Clarke's Nutcracker, Piñon Jay, Western Evening Grosbeak, Rocky Mountain Pine Grosbeak, Cassin's Finch, Crossbill, Mexican Crossbill, Brown-capped Rosy Finch, Goldfinch, Pale Goldfinch, Pine Siskin, Gray-headed Junco, Mountain Song Sparrow, Cañon Towhee, Water Ousel, Cañon Wren, Rocky Mountain Creeper, Rocky Mountain Nuthatch, Red-Breasted Nuthatch, Pygmy Nuthatch, Gray Titmouse, Long-tailed Chickadee, Mountain Chickadee, Lead-colored Bush-Tit, Townsend's Solitaire.

B—Summer residents, migrating south in winter, 84 species. Sora, Killdeer, Mountain Plover, Western Mourning Dove, Turkey Vulture, Sharp-shinned Hawk, Cooper's Hawk, Krider's Hawk, Western Redtail, Swainson's Hawk, Prairie Falcon, Duck Hawk, Sparrow Hawk, Burrowing Owl, Belted Kingfisher, Red-naped Sapsucker, Williamson's Sapsucker, Red-headed Woodpecker, Poor-will, Western Nighthawk, White-throated Swift, Broad-tailed Hummingbird, Rufous Hummingbird, Kingbird, Arkansas Kingbird, Cassin's Kingbird, Ash-throated Flycatcher, Say's Phoebe, Olive-sided Flycatcher, Western Wood Peewee, Western Flycatcher, Traill's Flycatcher, Least Flycatcher, Hammond's Flycatcher, Wright's Flycatcher, Cowbird, Yellow-headed Blackbird, Thick-billed Redwing, Bullock's Oriole, Brewer's Blackbird, Bronzed Grackle, Arkansas Goldfinch, Arizona Goldfinch, Mexican Goldfinch, Western Vesper Sparrow, Western Savannah Sparrow, Western Lark Sparrow, White-crowned Sparrow, Western Chipping Sparrow, Brewer's Sparrow, Lincoln's Sparrow, Green-tailed Towhee, Black-headed Grosbeak, Western Blue Grosbeak, Lazuli Bunting, Lark Bunting, Western Tanager, Cliff Swallow, Barn Swallow, Tree Swallow, Violet-green Swallow, Rough-winged Swallow, White-rumped Shrike, Western Warbling Vireo, Plumbeous Vireo, Virginia's Warbler, Orange-crowned Warbler, Yellow Warbler, Audu-

bon's Warbler, Black-throated Gray Warbler, MacGillivray's Warbler, Western Yellow-throat, Long-tailed Chat, Pileolated Warbler, Redstart, Pipit, Mockingbird, Catbird, Brown Thrasher, Rock Wren, Western House Wren, Ruby-crowned Kinglet, Audubon's Hermit Thrush, Chestnut-backed Bluebird.

C—Birds which breed within the County, and occasionally winter, though usually going further south, 7 species. Spotted Sandpiper, Marsh Hawk, Lewis's Woodpecker, Western Meadowlark, Mountain Towhee, Western Robin, Mountain Bluebird.

D—Birds not known to breed within the County, but found more or less commonly in winter, 28 species. Wilson's Snipe, Goshawk, Western Goshawk, Rough-legged Hawk, Bald Eagle, Pigeon Hawk, Richardson's Pigeon Hawk, Short-eared Owl, Rocky Mountain Screech Owl, Gray-crowned Rosy Finch, Hepburn's Rosy Finch, Black Rosy Finch, Redpoll, Alaska Longspur, Chestnut-collared Longspur, McCown's Longspur, Western Tree Sparrow, White-winged Junco, Slate-colored Junco, Intermediate Junco, Shufeldt's Junco, Montana Junco, Pink-sided Junco, Arctic Towhee, Bohemian Waxwing, Northern Shrike, Prairie Marsh Wren, Western Golden-crowned Kinglet.

E—Birds not known to breed within the County, but more or less regular transients passing through in spring and autumn, 52 species. Eared Grebe, Pied-billed Grebe, Loon, Black-throated Loon, Ring-billed Gull, Forster's Tern, Black Tern, White Pelican, Merganser, Mallard, Gadwall, Baldpate, Green-winged Teal, Blue-winged Teal, Cinnamon Teal, Spoonbill, Pintail, Redhead, Canvas-back, Lesser Scaup, Golden-eye, Buffle-head, Ruddy Duck, Bittern, Great Blue Heron, Snowy Egret, Black-crowned Night Heron, Little Brown Crane, Coot, Northern Phalarope, Wilson's Phalarope, Long-billed Dowitcher, Baird's Sandpiper, Least Sandpiper, Semi-palmated Sandpiper, Greater Yellow-legs, Yellow-legs, Western Solitary Sandpiper, Western Willet, Long-billed Curlew, Black-bellied Plover, Baird's Sparrow, Western Grasshopper

Plate III.

Fig. 5. *E. R. W., Photo.*
YOUNG WESTERN HORNED OWL.
Delta County, Colo.

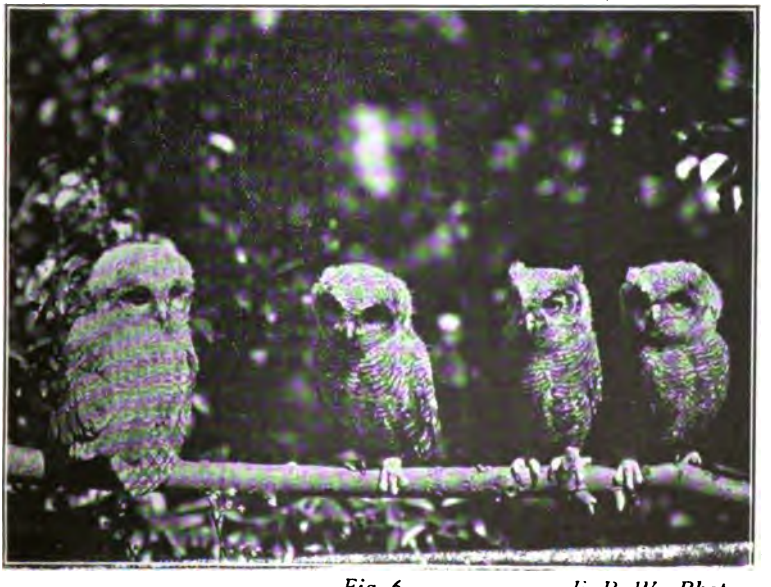

Fig. 6. *E. R. W., Photo.*
YOUNG AIKEN'S SCREECH OWLS.
Colorado Springs.

Fig. 7. *E. R. W., Photo.*
NEST AND EGGS OF BURROWING OWL.
Adams County, Colorado.

Sparrow, Gambel's Sparrow, Clay-colored Sparrow, Cassin's Vireo, Tennessee Warbler, Myrtle Warbler, Black-poll Warbler, Willow Thrush, Olive-backed Thrush, Alaska Hermit Thrush.

F—Birds not known to breed in the County, which have been taken or seen on from one to half a dozen occasions, 51 species. Bonaparte's Gull, Double-crested Cormorant, Hooded Merganser, Ring-necked Duck, White-winged Scoter, Snow Goose, Greater Snow Goose, Canada Goose, Hutchins's Goose, Whistling Swan, Least Bittern, Egret, Reddish Egret, Sandhill Crane, Florida Gallinule, Stilt Sandpiper, White-rumped Sandpiper, Upland Plover, Golden Plover, Band-tailed Pigeon, Swallow-tailed Kite, Mississippi Kite, Osprey, Spotted Owl, Flammulated Owl, Arctic Horned Owl, Black-billed Cuckoo, Red-bellied Woodpecker, Black-chinned Hummingbird, Calliope Hummingbird, Gray Flycatcher, Blue Jay, Crow, Bobolink, Rusty Blackbird, Snow Bunting, Harris's Sparrow, Dakota Song Sparrow, Swamp Sparrow, Indigo Bunting, Dickcissel, Scarlet Tanager, Bank Swallow, Cedar Waxwing, Prothonotary Warbler, Northern Parula Warbler, Oven-bird, Sage Thrasher, Baird's Wren, Western Gnatcatcher, Bluebird.

G—Species formerly occurring in the County, but now exterminated or not seen for many years, 3 species. Columbian Sharp-tailed Grouse, Merriam's Turkey, White-necked Raven.

H—Introduced species, 4. Bob-white, California Quail, Ring-necked Pheasant, House Sparrow.

ACKNOWLEDGMENTS.

We wish to acknowledge help or notes from the following:

The Bureau of the Biological Survey, U. S. Department of Agriculture, through its Chief, Mr. H. W. Henshaw, and Assistant Ornithologist, Mr. H. C. Oberholser, has identified various specimens for us, mention of which is usually specifically made in the text.

Mr. William Brewster has kindly examined his notes made

in 1882, looking up certain points for us. Mr. Alex. Wetmore sent a manuscript list of the birds observed by himself and R. B. Rockwell at Palmer Lake, September 5 and 6, 1909, with permission to make any use we desired of it. Dr. Edward C. Schneider of Colorado Coollege was good enough to read over the account of the life zones and give suggestions as to the characteristic plants, while much information was gathered from his "Distribution of Woody Plants in the Pike's Peak Region." Mr. Lloyd L. Shaw has permitted the use of manuscript notes made about Colorado Springs and in Crystal Park as well as the photographs of the young Sharp-shinned Hawks. Mr. Clark Mellen of New York has kindly given information as to the introduction of game birds at Glen Eyrie.

The cuts of the Long-eared Owl, Horned Owl, Burrowing Owl's Nest, Three-toed Woodpeckers, Nighthawk on the ground, the two of the young Magpies and the Magpie's nest, and the two cuts of Cliff Swallow's nests, were loaned by the "Condor," published by the Cooper Ornithological Club of California.

EXPLANATION.

The nomenclature of the American Ornithologists' Union has been strictly adhered to in this list, except in the case of the Juncos, where it was departed from for reasons there stated.

It should be stated that Monument Valley Park, frequently mentioned herein, refers to the park of that name in the city of Colorado Springs, and not to Monument Park, some six miles north of the city, and the location of the Woodmen's Sanatorium.

Whenever the Aiken Collection is mentioned, the collection of birds purchased from C. E. Aiken by General William J. Palmer and presented to Colorado College is referred to. It comprises the results of Aiken's collecting from his arrival in 1871 until 1907.

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Has some El Paso County notes.

Colymbus nigricollis californicus. Eared Grebe. "Hell Diver."

A regular migrant in spring and fall, arriving in spring about May 1. The autumn migration begins in September and continues for a couple of months, the latest date we have being October 27, 1906.

As there are not many bodies of water suitable for aquatic birds in the County the opportunity for obtaining notes on these forms has not been as good as might be desired, and especially has this been the case in the past. Various reservoirs have been constructed for irrigation purposes during the last few years which are attracting more birds during migration. This explanation will account to some extent for the paucity of notes on this and the following species of aquatic birds.

The grebes would no doubt breed in the County if there were any suitable places, as they breed in many localities in Colorado.

In the early days of Colorado Springs there were a couple of reservoirs on East Boulder Street, on ground now well settled. It is interesting to note that Warren killed an Eared Grebe on one of these reservoirs, October 23, 1882.

Podilymbus podiceps. Pied-billed Grebe. "Hell Diver."

A regular migrant, but not as common as the Eared Grebe.

Gavia immer. Loon.

Rare migrant. Aiken has had several adults brought to him, one of them in spring. It has been seen on Prospect Lake.

Gavia arctica. Black-throated Loon.

A not uncommon migrant, mainly in autumn. All that

Fig. 8. *E. R. W., Photo.*
LONG-EARED OWL, YOUNG JUST FROM NEST.
Hooper, Colo.

Fig. 9. *E. R. W., Photo.*
YOUNG ALPINE THREE-TOED WOODPECKERS.
Buffalo Pass, Colo.

Plate VI.

Fig. 10. *E. R. W., Photo.*
WESTERN NIGHTHAWK.
North Park, Colo.

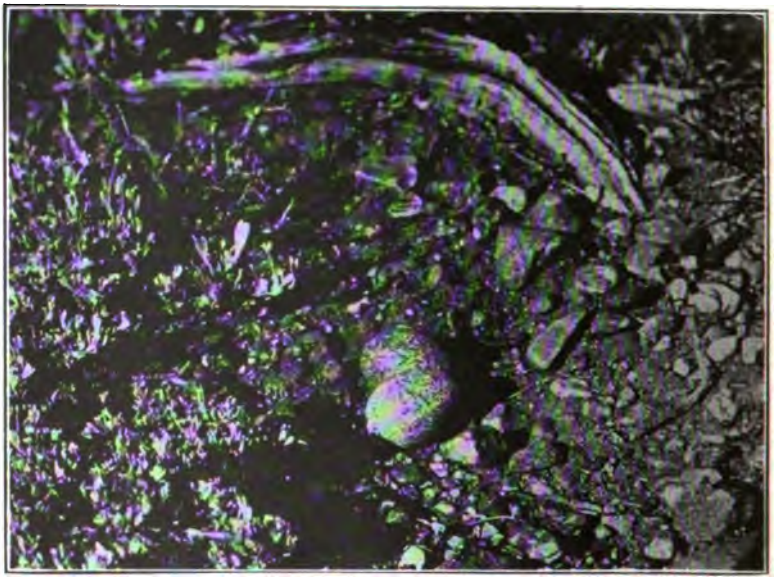

Fig. 11. *E. R. W., Photo.*
"NEST" AND EGGS OF WESTERN NIGHTHAWK.
North Park, Colo.

have been examined were immature birds. Aiken has had a good number brought to him during recent years. Three were killed on Prospect Lake, Colorado Springs, in November, 1898. There is a mounted specimen in the Aiken Collection, Colorado College Museum, which was sent in the flesh from Monument, May 11, 1901, and presumably killed near that place.

Larus delawarensis. Ring-billed Gull.

A common migrant, usually appearing in April. It has been taken from March 10 to May 16 in spring, and from September 7 to November 6 in autumn. There are three specimens in the Aiken Collection, two taken near Colorado Springs, the other labeled as from El Paso County. C. E. Eldredge brought one to Aiken, January 2, 1890, recently taken at his ranch in Chico Basin. An unusual date.

Larus philadelphia. Bonaparte's Gull.

Rare; but few have been taken in the County.

Sterna forsteri. Forster's Tern.

Rare. "Taken at intervals, according to Mr. Aiken." Allen and Brewster. The preceding note, published in 1883, holds good today. We have no recent records for the County.

Hydrochelidon nigra surinamensis. Black Tern.

A not uncommon migrant. Aiken saw two at a reservoir near Skinner's, southeast of Colorado Springs, July 30, 1907, and there is a mounted specimen in the Aiken Collection taken at Fountain, August 7, 1908.

Phalacrocorax auritus auritus. Double-crested Cormorant.

Rare. Has been taken occasionally near Colorado Springs in migration. One was shot near Fountain, October 21, 1901, by George Wright.

Pelecanus erythrorhynchos. White Pelican.

A not uncommon migrant, spring dates range from April

27 to June 10, and autumn dates from September 18 to October 13. A flock of 18 came to Prospect Lake, May 22, 1898, and 9 were killed. A large flock was reported to Aiken on the Johnson Reservoir, southeast of Colorado Springs, in first week in June, 1907, which remained there several days.

Mergus americanus. American Merganser. Sheldrake.

A not uncommon migrant; most of Aiken's records are in the autumn, one as late as November 27, 1905.

Lophodytes cucullatus. Hooded Merganser.

An immature bird of this species was brought to Aiken several years ago, which had been killed near Colorado Springs. This is the only record we have of its occurrence in the County, but it occurs occasionally over the eastern part of the State.

Anas platyrhynchos. Mallard.

A common migrant, occasionally winters where there is open water. Seven were seen on a pond in Monument Valley Park April 9, 1913.

In February, 1895, Aiken visited Clear Lake, near Deseret, Utah, before the marshes had thawed. Towards evening ducks flying high and coming from different directions at intervals were observed to drop down to a certain part of a frozen marshy meadow. He approached cautiously to investigate when twenty Mallard drakes suddenly raised their heads from above the grass and leaped into the air. They had apparently come to this spot to sleep and were huddled as closely together as possible.

Chaulelasmus streperus. Gadwall. Gray Duck.

Migrant, one of the most common ducks in spring and autumn, beginning to fly north the middle or latter part of March, and to come south again in late September. There is one in the Aiken Collection, taken near Falcon, May 3, 1907.

and Aiken saw one near Calhan in June, which was probably breeding.

Mareca americana. Baldpate. Widgeon.

A common migrant, at about the same dates as the Gadwall.

Nettion carolinense. Green-winged Teal.

A common migrant, coming the last of March in spring, and mid-September in autumn.

October 26, 1882, I killed one in the Colorado Springs City irrigating ditch, where it ran along the west side of what is now the D. Russ Wood Addition, and entirely built over, then there was not a house within several hundred yards. (E. R. W.)

It has recently been seen on the reservoir in Monument Valley Park. As of course no shooting is allowed in the park the ponds there should become a refuge for water fowl.

Querquedula discors. Blue-winged Teal.

A common migrant. Aiken found a nest, without eggs, June 4th, 1898, on Big Sandy Creek, near Ramah, on the plains, forty miles northeasterly from Colorado Springs. A pair were seen on the Monument Valley Park reservoir, May 10, 12, 14 and 23, 1913, giving rise to the hope that they might be nesting somewhere near, which was never verified, however. The species has also been seen at the same place in autumn.

Querquedula cyanoptera. Cinnamon Teal.

Formerly common migrant, now rare. Aiken does not see as many specimens now as once, but possibly this is because of the closing of spring shooting, most of the birds for mounting having been brought in in the spring. Aiken's last records are April 25, 1886, and March 26, 1887.

Spatula clypeata. Shoveller. Spoonbill.

Rather a common migrant. Has been taken as late as October 30.

Dafila acuta. Pintail.

A common migrant, and about the first of the ducks to appear in spring, often arriving early in February. Comes south in October. A male seen on Monument Valley Park reservoir, May 6, 1913.

Marila americana. Redhead.

A rather common migrant.

Marila valisineria. Canvas-back.

Migrant; not common.

Marila affinis. Lesser Scaup Duck. Little Blue-bill.

Common migrant. One seen on Monument Valley Park reservoir April 20, 1913, and two October 12, 1913.

Marila collaris. Ring-necked Duck.

Rare migrant. A few have been brought to Aiken.

Clangula clangula americana. Golden-eye.

A casual migrant. Aiken had specimens brought to him taken March 3, 1900, and December 14, 1906.

Charitonetta albeola. Buffle-head.

A common winter visitor.

Oidemia deglandi. White-winged Scoter.

There is but one record of the occurrence of this species in the County, a specimen which was killed on the Johnson reservoir near Skinner's, October 16th, 1907, and mounted by Aiken.

Erismatura jamaicensis. Ruddy Duck.

A rather common migrant, arriving late in spring. One was killed on Prospect Lake in the spring of 1912. Two males seen on Monument Valley Park reservoir, April 17, 1913.

Chen hyperboreus hyperboreus. Snow Goose.

Occasional. Aiken has a mounted specimen killed at the Pebbles Ranch on Squirrel Creek, 25 miles east of Colorado Springs, October 27, 1885.

Chen hyperboreus nivalis. Greater Snow Goose.

October 16, 1913, a flock of 9 or 10 geese came to the reservoir on the Stevenson ranch, 12 miles south of Colorado Springs, and two of them were shot by C. F. Anderson and Alex. Meredith of Colorado Springs. A third which was crippled on the 16th was secured by R. A. Barton on the 19th. This last bird is mounted and has been examined by Warren, as also the mounted head of one of the other two. The mounted bird and one of the others were measured when killed, their lengths being 28 and 30 inches respectively. The lengths of the bills of the two specimens seen, with the length of the wing of the mounted bird, together with the total lengths above given, indicate that the birds were Greater Snow Geese, and they constitute a third record of the species for Colorado, the other two being a bird taken by President Z. X. Snyder east of Greeley, March 20, 1895, and one killed by John F. Campion near Loveland, April 9, 1899. All three of the birds lately taken seem to be immature, having considerable yellowish on the feathers of the head and anterior portions of the body.

Branta canadensis canadensis. Canada Goose.

Reported by hunters who distinguish this form from the following.

Branta canadensis hutchinsi. Hutchins's Goose.

Occasionally killed by hunters who report it as more common than the Canada Goose. Aiken killed one from a flock at Chico Basin, December 3, 1871.

Olor columbianus. Whistling Swan.

Occasional migrant. An immature bird was killed on

Prospect Lake, November, 1910. It is now mounted and in the Aiken Collection at Colorado College.

Plegadis guarana. White-faced Glossy Ibis.

Rare; two killed by Charles Eldredge at his ranch in Chico Basin southeast of Colorado Springs, October 10, 1890.

Mycteria americana. Wood Ibis.

Rare; Aiken has three specimens in his private collection, all immature birds shot near Colorado Springs in August about 25 years ago.

Botaurus lentiginosus. Bittern.

Rather uncommon from lack of suitable conditions. Arrives in April, leaves in September and October.

Ixobrychus exilis. Least Bittern.

Rare, but two specimens being recorded from the County. One of these was taken near Colorado Springs somewhere about 1886; this was the first specimen of the species to be recorded from Colorado. The other was taken at Colorado Springs, June 18, 1907. This bird was found in a yard, alive, but injured, probably from having flown against a telegraph or telephone wire. Both specimens are mounted and in the Aiken Collection.

Ardea herodias herodias. Great Blue Heron.

Migrant, rather common, arriving early in April; the earliest date is April 2, 1889. No breeding colonies have ever been known in the County. November 27, 1897, a young bird was sent Aiken from Divide Station, on the Colorado Midlandn Railway, 9,200 feet altitude. An unusually late record for the species. This locality is in Teller County. The latest El Paso County date is November 2.

Herodias egretta. Egret.

The first instance known of the occurrence of this species

in the County, as well as in Colorado, is a single bird seen May 12, 1899, by Messrs. A. Gruber and F. Cikanck, taxidermists then in the employ of Mr. Aiken, in a cottonwood tree five miles south of Colorado Springs. As they were familiar with the species as well as with the more common *E. candidissima,* there seems no reason to doubt their identification.

Charles O'Connor saw three birds near a pond on the prairie 14 miles east of Colorado Springs, September 25, 1912, which seem to have been this species rather than the smaller Snowy Heron.

Egretta candidissima. Snowy Egret.

A not uncommon migrant, occurring irregularly in spring. The earliest date is May 2, 1899, and six birds of this species are known to have been killed in the vicinity of Colorado Springs that spring. Aiken has received a number of specimens from the mountains, indicating that it ranges as high as 10,000 feet.

Dichromanassa rufescens. Reddish Egret.

Accidental. There is a single record of the capture of this species in the County and in Colorado. This is a juvenile or immature bird which was brought to Aiken in the flesh, about August, 1875, and which had been killed near Colorado Springs.

Nycticorax nycticorax nævius. Black-crowned Night Heron.

A not uncommon spring migrant. A Black-crowned Night Heron with a broken wing was seen in a tree in Monument Valley Park, April 16, 1911. One was seen in the same park, April 9, one April 27, and two more May 10, 1913.

Grus canadensis. Little Brown Crane.

Taken occasionally near Colorado Springs. A flock of 15 was seen near Fountain by Dr. Heiple, about September 29th, 1913, one of which was killed and brought to Aiken.

One was killed at Curr's ranch south of Colorado Springs, March 27, 1900, and another near the city the following day.

Grus mexicana. Sandhill Crane.

Rare. One specimen which was killed near Colorado Springs early in 1885 was mounted by Aiken. Hunters claim that they have distinguished this species from the Little Brown Crane in the County.

Rallus virginianus. Virginia Rail.

A rather uncommon resident, winters about sloughs along Fountain Creek. Several seen and one secured near Skinner's ranch, January 15, 1908, by Aiken. This was the morning after a severe snowstorm, with temperature 10 below zero There is also a male specimen in the Aiken Collection shot February 16, 1899, in severe stormy weather. These birds were among rushes weighted with snow but near springholes with open water. He obtained a male with its nest and 7 eggs near Fountain, June 4, 1872.

Porzana carolina. Sora.

Common summer resident in suitable localities. Has been seen near Peyton by Aiken, July 17, 1897.

Gallinula galatea. Florida Gallinule.

The only record for the County and the State is the one mentioned by Allen and Brewster, who say: "Saw one in the flesh, taken May 9, [1882]." Presumably taken in El Paso County, though the precise locality is not indicated.

Fulica americana. Coot. Mud-hen.

Common migrant, possibly breeding in suitable localities.

Lobipes lobatus. Northern Phalarope.

Rare migrant in spring, specimens taken May 14th and 29th, are in the Aiken Collection.

Steganopus tricolor. Wilson's Phalarope.

Formerly not uncommon. Aiken found them near Foun-

Fig. 12. *E. R. W., Photo.*
BROAD-TAILED HUMMINGBIRD ON NEST ON ELECTRIC LIGHT FIXTURE ON PORCH.
Colorado Springs.

Fig. 13. *E. R. W., Photo.*
YOUNG WESTERN NIGHTHAWKS.
Gunnison County, Colo.

Plate VIII.

Fig. 14. *E. R. W., Photo.*
YOUNG KINGBIRD.
Colorado Springs.

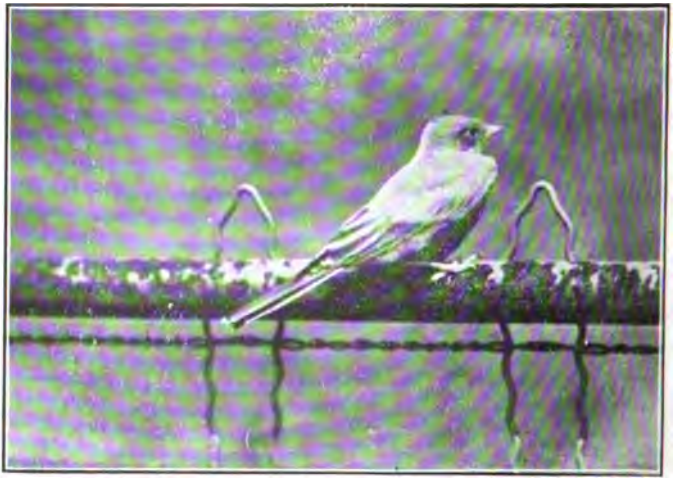

Fig. 15. *E. R. W., Photo.*
YOUNG SAY'S PHŒBE.
Colorado Springs.

tain in 1873, and specimens were occasionally brought to him in Colorado Springs in the eighties, but none since July 17, 1888. It is not at all uncommon in some sections of Colorado, and breeds in various places in the State.

May 19, 1911, Warren saw 25 or 30 Wilson's Phalaropes on a small pond or reservoir at a ranch about twelve miles southwest of Elbert. This possibly may have been in Elbert County; at all events it was very close to the line.

Recurvirostra americana. Avocet.

Migrant; not uncommon.

Aiken witnessed a curious performance of Avocets in Utah. In September, 1893, he visited the mouth of Bear River where hundreds of acres of mud flats and shallow water offer an attractive resort for various water fowl. In a submerged grove where patches of mud appeared above the water hundreds of Avocets were congregated. One little mud island that differed from others in that it was quite round seemed to have a fascination for the birds, and they were packed together upon it in a mass which covered the island to the water's edge. As the island was about 12 feet in circumference the number of birds probably approximated 150. This mass of birds continued to revolve about from left to right, and being so crowded the movement was rather slow and their steps short and measured, so that the impression was that they were all marking time in the marching. Birds on the rim of the circle avoided walking off in the water and crowded inward against the mass. Every moment or two birds would leave the milling body and fly to a neighboring mud island, and as many from near by would fly to take their places and join the dance. Aiken advanced quietly to within 20 yards and viewed them for half an hour, but they continued undisturbed by his presence and he left them so. It appeared to be a diversion of the birds.

The flesh of Avocets is not esteemed in places of their abundance. Most of them are infested with worms which

are found not only in the digestive tract but in the abdominal cavity and the eye sockets. The flavor is rather fishy.

Philohela minor. Woodcock.

August 16, 1898, Aiken flushed a bird in oak brush on the Starr Ranch on the slope of Cheyenne Mountain which he believes to have been a Woodcock. He was also informed that two men hunting on Rock Creek killed two Woodcock. The Woodcock is known to occur rarely in the northern part of the State. Cooke mentions five records from the neighborhood of Denver.

Edward H. Eyre says that while trout fishing in Manitou Park about September first some years ago he plainly saw a pair of Woodcock on the ground among willows bordering the stream. This was about 30 miles west of Colorado Springs in Teller County.

Gallinago delicata. Wilson's Snipe. Jack Snipe.

Common migrant and winter resident.

Wilson's Snipe is known to breed in favored localities throughout the State on the plains and up to 9,500 feet in the mountains, but there are no very suitable breeding grounds for it in El Paso County. They begin to make their appearance the last of August or first of September at the first autumn storm and become plentiful in October. Many go further south by the first of November but a great many remain through the most severe winters, some until the first of May.

Fountain Creek rarely freezes over entirely below its exit from the mountains, and along its banks there are many places where water that runs through the sand comes to the surface and forms springy holes and marshy meadows which are warmer than surface water. These become the winter feeding grounds for the Snipe and one or a pair often content themselves with a very small area of muck. But at times of severe cold many of the smaller holes freeze and then the Snipe concentrate at places where a larger flow of water keeps

the holes open. On January 15, 1908, with six inches of snow on the ground and below zero weather Aiken visited a small beaver pond on the Skinner ranch six miles south of Colorado Springs. A bit of marsh above the pond and a short stretch of ooze along the outlet below remained open, and in this small area of one-fourth of an acre were 25 to 30 Snipe. Some years ago a Snipe was found running upon the ice when everything in the vicinity was frozen solid. A few Snipe winter along banks of streams in the mountains.

That Snipe know enough to protect themselves from storms may be illustrated by narrating here one of Aiken's experiences in Utah about 20 years ago. He was beating a snipe marsh near one edge of which extended a narrow arroyo or gully in which were some trees and bushes. The weather had been fair until without warning a heavy snow storm set in. At once Snipe began to rise wildly from different parts of the marsh and one after another directed their flight toward the same point in the arroyo and dove between its banks. Upon investigation 8 or 10 Snipe were found together in a little cave in the side of the arroyo that was partly hidden by bushes so that they were well protected from any storm. We conclude this was not the first time the Snipe had resorted to this friendly shelter since they knew so well where to go.

Macrorhamphus griseus scolopaceus. Long-billed Dowitcher.

Migrant, not common.

Micropalma himantopus. Stilt Sandpiper.

The only record for the County is a female in the Aiken Collection, taken near Colorado Springs, May 14, 1884.

Pisobia fuscicollis. White-rumped Sandpiper.

A single record for the County, one taken by Aiken at Colorado Springs, and identified by Ridgway.

Pisobia bairdi. Baird's Sandpiper.

Common migrant. It makes its appearance in the autumn

migration late in July, there being a mounted bird in the Aiken Collection, taken at Skinner's ranch, July 29, 1907.

Pisobia minutilla. Least Sandpiper.

Rather common migrant.

Ereunetes pusillus. Semipalmated Sandpiper.

Uncommon migrant. Allen and Brewster mention seeing a fresh specimen at Aiken's, taken May 1, 1882.

Totanus melanoleucus. Greater Yellow-legs.

Rare. One noted by Aiken April 10, 1908, near Colorado Springs.

Totanus flavipes. Yellow-legs.

Not uncommon migrant. Allen mentions taking a single specimen each of this and the preceding species at Palmer Lake, August 5, 1871, and states that they were the only individuals seen of either species, a rather strange coincidence.

Helodromas solitarius cinnamomeus. Western Solitary Sandpiper.

Rather common spring migrant. It was seen in Monument Valley Park, May 26 and August 10, 1913, a single bird on each occasion. Aiken's earliest spring date is May 4, 1900, and earliest summer date July 23, 1899.

Catoptrophorus semipalmatus inornatus. Western Willet.

Common migrant in spring.

Bartramia longicauda. Bartramian Sandpiper. Upland Plover.

The title of the Upland Plover to a place in this list rests on the record of Allen and Brewster which says "Large numbers were brought in by gunners April 28, [1882]." Aiken has no personal knowledge of its occurrence here nor has he

met with it in his explorations on the plains to the eastward. It has, however, been reported by Hersey and Rockwell at Barr, near Denver, about ninety miles north. Aiken found it common in South Park, Park County, in 1872, at the Salt Works in July, and along the road from Fairplay to Hartsel in August.

Actitis macularius. Spotted Sandpiper.

A common summer resident along the streams, arriving about May first. Aiken stated in 1872: "Common summer resident, a few remain during the winter." There is no other winter record than this, but it is no doubt correct. There are no actual breeding records for the County, but it undoubtedly does breed. First appeared in Monument Valley Park in 1913, May 4, and seen regularly after that whenever the park was visited, the latest date when they were seen being September 10. Two were seen at Lake Moraine, 10,250 feet, September 2, 1905, by Warren, and Aiken saw a pair there July 10, 1899.

Numenius americanus. Long-billed Curlew.

Formerly a common summer resident, breeding on open prairies, now a rare migrant near Colorado Springs. Aiken noted one on the Broadmoor ranch May 4, 1899. Sclater's reference of the Hudsonian Curlew to El Paso County is erroneous, the specimen in question proving to be an immature bird of the present species.

Squatarola squatarola. Black-bellied Plover.

A rare migrant, taken but a few times, once by Aiken in 1884 or 1885, and one or two others have been brought to him to be mounted.

Charadrius dominicus dominicus. Golden Plover.

But one known occurrence in the County, one or two taken by Aiken near the Boulder Street reservoir, Colorado Springs, about 1875, in the late autumn.

Oxyechus vociferus. Killdeer.

A common summer resident, arriving sometime in March, and mainly leaving in the fall by October first, but a few remain much later. An early record is February 17, 1909, at Piñon, Pueblo County, just south of our boundary. Most common at low elevations.

Podasocys montanus. Mountain Plover.

Formerly a common summer resident.

In the early eighties a number of pairs nested on the prairie land just north of Colorado Springs that is now built over by the growing city. None have been reported near the city for twenty years but there are a few breeding in the eastern part of the County. Aiken saw a female bird and newly hatched young at Ramah, June 7, 1898, and O'Connor says one or two pairs bred near his ranch 10 miles east of Fountain in 1913. Aiken found a nest with three fresh eggs 30 miles east of Colorado Springs May 25, 1878, which his notes state "was discovered beside the road through the anxiety displayed by the parent bird. The eggs were laid upon several soft leaves of the prairie thistle with no other semblance of a nest save the slight depression in the ground."

The Mountain Plover differs greatly in habits and characteristics from its near relative the Killdeer. It shows no preference for wet ground but on the contrary frequents mesas or high rolling prairie land, often remote from water. Their manner is quiet; they have no wailing cry; they run rapidly a short distance and stand silent and motionless with the head sunk low on the shoulders. Their unspotted plumage blends with the color of the dry grass and parched ground and makes them difficult to discover.

But in August, when the young birds shift for themselves, they gather in flocks and repair to the vicinity of water holes and flooded fields. Cooke cites the fact that Captain Thorne shot 126 in one day at this season as evidence of the abundance of this species, but that is not a fair basis for

such a conclusion. A flock from which many may be killed at a single shot represents birds bred over an extended area.

The name of "plover" places this species in the class of game birds which may be shot in the open season. As a game bird in spring it compares with the horned lark but has some advantage as to size, and presents an attractive mark to the amateur shooter.

Colinus virginianus virginianus. Bob-white.

Not a native species but has been introduced at various times. General Palmer turned out a number from Glen Eyrie, bringing them from Kansas and Oklahoma. Mr. Clark Mellen writes us that a good many broods were seen about the place the first year but only a few the second. It is difficult to say what became of them, they may have died from lack of food, exposure in winter, or been killed by lawless hunters. E. A. Touzalin liberated some about 25 years ago at his ranch on Cheyenne Mountain, and these seem to have scattered about considerably. Ten years ago there were some on the Bates ranch south of Colorado Springs, on Fountain Creek, also about 15 years ago there were some on a ranch farther south, about 45 being seen there one day in January, 1898. One was heard near Buttes, July 9, 1907, and one May 10, 1908, and there are still a few in that region. These are descended from birds liberated about 1888 by R. R. Taylor of Colorado Springs. A pair of Texan Bob-whites from Texas were liberated near Colorado Springs in 1898 by George Bonbright, but it is not believed that they survived.

There is not a great deal of cover for the birds and it is easy for hunters who have no regard for the law to kill them. Horned Owls are also partly responsible for their extermination. Dead Quail have been found in Owls' nests on Fountain Creek.

Bob-whites are plentiful in western Kansas and in recent years have spread westward over the Colorado line at several points where there is sufficient cover in this State to afford

them protection. They have become plentiful along the Arkansas Valley since its settlement and cultivation as far west as least as La Junta where Aiken saw many in June, 1908. They very probably may have extended as far west as Pueblo as conditions are favorable for them all along that valley, but it is not believed that any of the birds in El Paso County have come from that source.

Callipepla squamata squamata. Scaled Quail. "Blue Quail." "Mexican Quail."

Locally common; resident.

Until recent years the Scaled Quail has been generally known as restricted to the southern and central portions of New Mexico, Arizona, and western Texas, yet as long ago as May, 1876, Aiken learned of it as a common resident along the Purgatoire River north of Trinidad in Colorado. It was not recorded from the State, however, until 1895 when W. P. Lowe noted in the Auk, XII, p. 298, his finding one in the Wet Mountains southwest of Pueblo. Previous to this, in 1884, T. S. Brigham of Colorado Springs liberated several pairs on his ranch west of Fountain, but it is not known that any of these survived as they soon disappeared from the premises.

With the settlement and cultivation of the land along the Arkansas River east of Pueblo this quail coming in from the Purgatoire valley and the cedar hills east of it increased and spread rapidly. For twenty years they have been plentiful in the region of Rocky Ford and La Junta, later extending up the valley to Cañon City, and spreading northward. In the spring of 1908 Scaled Quail made their appearance in El Paso County in several localities. May 8 Aiken found a pair at the mouth of Bear Creek (later their nest with 18 eggs was found). A few days after this Sclater saw several near Glen Eyrie, and in June Scheutze learned that two or three had been shot along the mesa west of Colorado Springs.

Charles O'Connor reported that 42 had wintered at the Franceville coal banks, taking shelter at night in a deserted coal shaft. A surprising appearance was that of a pair at

the signal station on the summit of Pike's Peak on June second. The female was shot at the time, and the male lingering near was killed six days later. It is strangely at variance with the known habits of this bird that it should penetrate so far into the mountains, but this is not the only instance we have of its occurrence at high altitudes. In June, 1911, T. S. Brigham saw a covey near a ranch at Lake George, over 30 miles northwesterly from Colorado Springs, in the heart of the mountains, at 8,085 feet altitude. The ranchman told him they were reared there by a pair which came there the year before.

From the first appearance of these birds in El Paso County they multiplied rapidly. In the late autumn of 1911 packs of one or two hundred were reported near Fountain and Buttes. In defiance of the game law which then protected them until 1915, and which protection has since been extended to 1924, many were shot. Later in the winter snows which covered the ground for a week or two at a time deprived them of food. Whether they migrated or perished is uncertain, but there were few remaining the next year and they have not since been plentiful.

The Scaled Quail does not usually hide for protection but depends on its fleetness of foot to escape. On barren land to the southward where little vegetation grows besides the tree cactus they find a friendly shelter beneath the sharp-spined branches from the attacks of hawks. That many do fall victims to birds of prey is certain. A Goshawk from Pueblo County brought to Aiken February 15, 1909, contained in its crop one freshly eaten Scaled Quail, and in its stomach the remains of another.

As noted by Aiken the call note of this quail is *kuk chung* often repeated.

Lophortyx californica. California Quail.

An introduced species. E. A. Touzalin liberated some at his ranch on Cheyenne Mountain a number of years ago, and

General Palmer also turned some out at Glen Eyrie.

It is not known to which subspecies these birds belonged "California Quail" have for years been reported to occur in the neighborhood of Turkey and Little Fountain Creeks but none have been critically examined. They are no doubt the Scaled Quail as this is often called "California Quail" colloquially.

Dendragapus obscurus obscurus. Dusky Grouse.

Resident in the mountains; not common.

The Dusky Grouse was probably never as abundant in El Paso County as it is or has been in the mountains farther west. It is usually found above 8,000 feet. It winters in the green pine and spruce timber at the higher altitudes, but probably most of the broods are raised somewhat lower down. This species was no doubt killed by Pike when he made his attempt to get to the Peak. In his account he speaks of it as the "Pheasant."

Pediocetes phasianellus columbianus. Columbian Sharp-tailed Grouse.

This species is not now known to exist in El Paso County, though it was formerly common on Monument and Kettle Creeks and along the Divide. Allen states that it was said to be abundant, especially near Palmer Lake. This was in 1871. In 1875 they were still comparatively common in certain localities, and in September of that year Aiken found numerous tracks at Sand Creek, east of Colorado Springs, but failed to see any birds, though it had been reported that they were there. From Sand Creek he proceeded northward until he struck the headwaters of Kettle Creek, and there found a covey of seven or eight birds, from which one or two were secured. The farthest point south that the species has been seen about here is a bird flushed by Aiken near the Bates ranch 40 years ago.

Meleagris gallopavo merriami. Merriam's Turkey. Wild Turkey.

Formerly common in the foothills, now exterminated.

When Aiken located on his ranch in the Turkey Creek valley in November, 1871, he was told that Jeff Steel, the previous owner of the ranch, had killed one or more Wild Turkeys there the year previous. Years before that time the creek had received its name from the abundance of Turkeys there. In December, 1871, Aiken found evidence of the roosting place of a Turkey on the edge of Barnes's Canon two miles east of the ranch. In the spring of 1873 his mother, Mrs. J. E. Aiken, while riding horseback a short distance north of the ranch saw a Wild Turkey run across the road a few rods ahead of her. This is believed to have been the last survivor of the species in the County.

Of the host of Wild Turkeys which once inhabited the Front Range of the Rocky Mountains in Colorado none now remain except a few along the southern border of the State. Only one specimen from the devastated area remains, a mounted bird in the Colorado Museum of Natural History, Denver, which was killed in South Park, in January, 1878. This specimen and existing birds of the southern border have been identified as Merriam's Turkey, and beyond a reasonable doubt all the Turkeys indigenous to the mountains intervening between these points were of the same form.

Phasianus torquatus. Ring-necked Pheasant. Mongolian Pheasant.

An introduced species. General Palmer brought a number to Glen Eyrie, which after being kept confined for some time were liberated. A good number of young broods were seen about the first season, only a few the second, and eventually they about all disappeared. There are two or more in Monument Valley Park which have been there three or four years. In the fall of 1912 one was brought to Aiken which was killed near Palmer Lake. It seems quite certain that this in-

dividual may have wandered down from the north, as many have been liberated in the vicinity of Denver, where they have done fairly well and spread over considerable territory.

Columba fasciata fasciata. Band-tailed Pigeon.

No specimens of this bird have been taken in El Paso County and its possible occurrence rests upon the following reports: A flock was reported to Aiken as having been seen in Queen's Canon, about 1880; a couple were described as having been seen just west of Colorado Springs in the spring of 1905. The first specimen taken in the State was killed by Aiken at Del Norte, September 26, 1874. Three were seen and one reported killed by Sam Keaton on Little Fountain Creek in the autumn of 1910.

Zenaidura macroura marginella. Western Mourning Dove.

A common summer resident, arriving early in April and departing early in October. Found practically over the county in the more open country. Nests both on the ground and in trees. Keyser found a nest near Ramah in the same tree with nests of Eastern and Arkansas Kingbirds.

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Pt. 2

Charles E. H. Aiken
and
Edward R. Warren

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The Birds of El Paso County Colorado

By
CHARLES E. H. AIKEN
and
EDWARD R. WARREN
Director of the Museum, Colorado College

PART II

THE BIRDS OF EL PASO COUNTY, COLORADO

Cathartes aura septentrionalis. Turkey Vulture. Turkey Buzzard.

Summer resident; not common. Arrives early in April and departs late in October.

Turkey Buzzards are not as numerous in Colorado as 40 years ago, but it is no uncommon sight to see one soaring aloft near Colorado Springs in early spring and summer. They are not known to breed within the County, but there is a roost just beyond our lines at the Glendale crossing of Beaver Creek from whence our soaring birds probably come. This Glendale roost is very old; Aiken's notes state that he found 20 birds there in May, 1872. A specimen in the Aiken Collection was taken near Colorado Springs, April 12, 1911.

Elanoides forficatus. Swallow-tailed Kite.

Rare. The only known examples taken in the region were captured in August. In that month in 1877 two were brought in the flesh to Aiken, one of which had been shot at Colorado Springs, and the other at Manitou Park, Teller County.

Ictinia mississippiensis. Mississippi Kite.

Rare; the only record is one seen by Aiken, in Deadman's Cañon, southwest of Colorado Springs, during the summer of 1873.

Circus hudsonius. Marsh Hawk.

Summer resident; common. A few remain through the winter. Arrives as early as the latter part of February, and leaves in October. Rockwell and Wetmore, September 6, 1909 saw at Palmer Lake Marsh Hawks all day long, migrating, flying toward the southeast, sometimes singly, sometimes two or three together. Found on the plains and the more open spaces in the mountains. One was seen hunting on some vacant lots in the northerly part of Colorado Springs, Septem-

ber 28, 1913. Forty years ago birds in the mature blue plumage were frequently noted, now they are rarely seen.

Accipiter velox. Sharp-shinned Hawk.

Summer resident; not common. Arrives the first week in March, leaves some time in October. One was brought to Aiken December 21, 1913. This destructive little hawk is found about the trees and thickets along the streams, in the foothills, and the more open woods in the mountains up to above 8,000 feet.

A nest observed by Lloyd Shaw in Crystal Park contained, July 10, 1912, 3 young and one unhatched egg, the young having been hatched a few days previously. The nest was in a Douglass's fir tree about ten feet above the ground, and was an old magpie's nest the roof of which had been torn off, and the cup built up with small sticks until it was very shallow, not much more than a platform. The fourth egg, mentioned above, hatched after July 10, the young bird lived two days, and then disappeared. August first the three surviving young were of as many different sizes; they were still largely in the down, but the quills and retrices were about half out of their sheaths, and the breast markings showed quite distinctly on the largest bird. When disturbed at the nest they fluttered down toward the ground, but had no control over their flight, nor could they perch unaided, though they could sit upright on a perch when placed thereon.

The well-picked leg of an Audubon's Hermit Thrush was found in the nest on that date, and Shaw had previously found the feathers of a flicker below the nest. The disapperance of a young Three-toed Woodpecker from its nest not far away was also charged against the hawks.

August 25 and September 1, 1912, a male Sharp-shinned Hawk was seen in the Monument Valley Park. On the first date it was seen chasing a Brewer's Blackbird. On the latter date it was being mobbed by various small birds. Two Flick-

ers were there also and seemed as much afraid of the hawk as any of the others, though so near its own size. A number have been noted in the park and nearby the last year or two, especially in spring and autumn.

Accipiter cooperi. Cooper's Hawk.

Summer resident, not common, arriving in April. An early date is March 21, 1900.

Astur atricapillus atricapillus. Goshawk.

Winter resident, rather common.

Three specimens in the Aiken Collection, from Monument, near Colorado Springs, and El Paso County, respectively, are labeled as belonging to the typical form. How destructive this species can be to game and small birds is shown by the food of one killed near Piñon, February, 1909. The crop contained a freshly eaten Scaled Quail, and the stomach the partly digested remains of a Blackbird and another Scaled Quail.

Astur atricapillus striatulus. Western Goshawk.

Winter resident, rather common.

Four specimens in the Aiken Collection, two from Turkey Creek and two from near Colorado Springs are labeled as belonging to this subspecies.

Buteo borealis krideri. Krider's Hawk.

Summer resident, rare.

There are two Redtails in the Aiken Collection which have been referred to this subspecies, one taken near Colorado Springs, September 27, 1902, the other at Manitou Park, Teller County, August 29, 1906.

Buteo borealis calurus. Western Redtail.

Summer resident, common. Arrives the first of March,

departs the last of October (one specimen in the Aiken Collection taken October 28, 1872). Occasionally winters: one noted by Aiken, February 2, 1899.

One of our most common hawks, found everywhere during migration, but breeds in the mountains from the foothills upward. A very valuable bird economically as its food is largely mice and ground squirrels, and in spite of its common name of "Hen Hawk" it attacks poultry but little. It will kill animals as large as cottontails, and one was seen by Shaw near Crystal Park carrying a rabbit in its talons.

Buteo swainsoni. Swainson's Hawk.

Summer resident; common. Arrives in March and departs in August and September.

This is one of the most characteristic birds of the arid plains; a few go into the mountains, and there are several records of its breeding at high altitudes in various parts of the State, but we have no such records for El Paso County, as the portion of the range within our limits presents no open park-like areas such as they would likely prefer. They build their nests in the cottonwood trees bordering prairie streams or dry sand creeks. The nests are of moderate size, constructed mostly of coarse dead twigs and placed usually 12 to 15 feet above the ground; however, Aiken found one nest in 1878 on Horse Creek at an elevation of only six feet. On this occasion 8 or 10 nests were found in which laying had commenced in only three by May 17th. He found a newly finished nest without eggs June 4, 1898, near Calhan, and one May 15, 1904, at Ramah, which already held the full complement of three eggs. We may therefore state that laying takes place between May 10 and June 10.

Swainson's Hawk has the rather singular habit of placing two or three green cottonwood twigs with green leaves across the nest. These are placed in newly finished nests before any

eggs are laid, and also over newly laid eggs. The object of this gives rise to some speculation, but we conclude that it is for the purpose of disguise or concealment. One thing that supports this view is that the leaves are found quite fresh as though the bird had plucked the twigs on sighting the intruder.

Young birds are plentiful the latter half of July, but soon disappear with the adults. Nearly all Colorado breeding birds are of normal coloration but Aiken found a pair in the melanistic phase breeding at Resolis, Elbert County, May 26, 1899, described in his notes as "a dark chocolate colored pair, one darker than its mate." He saw one believed to be a migrant near Calhan August 30, 1907. A notable flight of melanistic hawks of this species took place in 1901. Following fair mild weather during February snowstorms prevailed during the forepart of March. On the morning of the eleventh of that month snow was quietly falling and the sun was obscured by a snow cloud. Word came to Aiken that ten dark-colored hawks were in the shade trees on Cascade Avenue near St. Vrain Street, and that a boy was shooting at them with a flobert rifle. Hastening to the locality indicated four hawks were seen perching in trees and five which had been killed by the young shooter were secured for preservation. They varied in general coloration from umber brown to umber black according to age and sex. Two of these specimens now in the Aiken Collection at Colorado College may be more particularly described:

No. 4507 (Orig. No.). Male. Above dark umber; below gray umber shaded with umber brown. Under wing coverts dark rufous. Under tail coverts rufous barred with paler and whitish. Length 18.5 ins.; Extent 46 ins.; Wing 14.5 ins.; Tail 7.8 ins.

No. 4508 (Orig. No.). Female. Umber black above and below. Under wing coverts paler, spotted with white. Under tail coverts white, barred with brown; rufous shades almost

entirely absent. Lenth 20.8 ins.; Extent 53.5 ins.; Wing 15.5 ins.; Tail 8.8 ins. Weight 40 ounces.

It was noted that the stomachs in all the specimens were quite empty.

A larger flock of melanistic hawks was seen in 1912 by Charles O'Connor who brought to Aiken a beautiful example shot by him a short distance east of Prospect Lake. He counted at that place 36 hawks within a limited area, all of the same form. This was on April 20, a bright sunny day succeeding a period of stormy weather. The hawks were sitting about on the open prairie and were engaged in catching grasshopper larvæ. He could also discern another flock similarly engaged so far away that he could not determine the variety. The specimen secured is a female similar in coloration to the one described above, and weighed two ounces more.

Archibuteo lagopus sancti-johannis. Rough-legged Hawk.

Winter resident, common. Arrives about November 1, and departs early in April.

A bird in the normal plumage was seen in Monument Valley Park, January 10 and 12, 1913.

Archibuteo ferrugineus. Ferruginous Rough-leg. Squirrel Hawk.

Resident, common; much more abundant in summer than in winter.

This hawk is a bird of the plains rather than of the mountains, living mainly on mice, ground squirrels, gophers, rabbits and prairie dogs, and is an exceedingly useful bird, rarely if ever attacking poultry or wild birds. While a number spend the winter with us, there are more about in summer, and it is quite possible that our summer birds leave in the autumn and that the winter residents come from farther north.

The breeding range of this species is coincident with that of Swainson's Hawk but incubation begins about two weeks earlier, eggs being found as early as April 15.

Aiken has had a number of specimens in the melanistic plumage, and there is a fine mounted example of this in the Aiken Collection at Colorado College.

Aquila chrysaëtos. Golden Eagle.

Resident, not uncommon, especially in winter.

These winter eagles come from the north and the mountains, and range out over the plains hunting jack rabbits and prairie dogs, while dead cattle and horses are not disdained.

A pair breed in North Cheyenne Cañon; they are said to have two eyries, one on either side of the cañon, and to breed in each in alternate years. About 1875 Aiken had Golden Eagle eggs brought to him which were obtained at the bluffs north of Colorado Springs.

The Golden Eagle is reported to be one of the worst enemies of the mountain sheep, killing many of their lambs. A Mr. Waldron told Aiken that many years ago when driving on the plains with several others he saw an eagle of this species attack and kill an antelope. The bird pursued a bunch of the animals, singling out one, and when close enough struck it on the back with its talons, and while clinging there and tearing with claws and beak it at the same time beat its prey's sides with its wings. The men drove close enough to shoot the eagle, and found the antelope to be dead with its back badly torn by the bird. Aiken was also told that an eagle was seen to pounce upon a two-year-old calf near Hartsel but was driven away before any harm was done. Rather large prey for the bird to tackle.

Haliætus leucocephalus leucocephalus. Bald Eagle.

Formerly quite common, but have been killed off.

An immature bird was brought to Aiken, which was killed at Buttes, January 10, 1910. The last full plumaged birds which were killed in the County were killed in 1904 and 1905, at the base of Cheyenne Mountain. Both were shot from the same tree by the same man, who had observed in the first mentioned year that the bird was in the habit of perching every day in the same pine tree. He had a blind nearly, went there before daylight, and killed the bird when it came. The following year he secured the second bird in the same way, from the same tree.

Falco mexicanus. Prairie Falcon. "Bullet Hawk." "Swift."

Summer resident, common. Arrives in April.

Breeds about rocky places, and a pair was known by Aiken to have nested in the rocks of the Garden of the Gods in 1874. Young birds are common in July and August. Seems to be confined to the plains region.

Falco peregrinus anatum. Duck Hawk.

Rare summer resident, and not common even in migration.

This hawk has been known to breed in the rocks at the Garden of the Gods, where Allen noted it in 1871. Aiken's attention was called to their presence in the place by Minot, in 1879, and he secured a specimen there shortly afterward, and also collected one there in 1884. One killed near Peyton in July, 1912, is now in the Aiken Collection at Colorado College, as are also the two specimens previously mentioned.

Falco columbarius columbarius. Pigeon Hawk.

Winter resident, not uncommon. Has been seen as early as September 21, and as late as May 7.

Pigeon Hawks sometimes come right into the heart of Colorado Springs, possibly attracted by an abundant food

supply in the shape of English Sparrows, which hardly anyone will begrudge them. December 22, 1911, one was seen on Tejon Street, between Bijou and Kiowa Streets, in the business district, and they are frequently seen farther away from that part of the city. All records are from the neighborhood of the foothills.

Falco columbarius richardsoni. Richardson's Pigeon Hawk.

Winter resident, not as common as the preceding.

Richardson's Hawk is a bird of similar habits to the common Pigeon Hawk, and frequents the same localities, living on the same sort of food, small mammals and small birds. A specimen killed near Colorado Springs was brought to Aiken in October, 1913.

Falco sparverius sparverius Sparrow Hawk.

Summer resident, common. Arrives the last of March, and leaves in October.

This species is hardly as common as it was years ago, before a bounty was placed on hawks, and which was in force for several years. This bounty law resulted in the decimation of this useful species. Since its repeal the birds have increased, but have hardly reached their former abundance. Still the Sparrow Hawk is a common summer bird throughout the County, seen along the roadsides perched on telephone poles and fence posts. Living as it does, very largely on mice and grasshoppers, it is one of the most useful birds we have, and of great value to the farmer. It nests in hollow trees, old woodpeckers' holes, magpies' nests, and natural rock cavities. Breeds on the plains wherever trees are found but is most numerous in the lower foothills, breeding indifferently in pines or cottonwoods. In the mountains it occurs less commonly to above 9,000 feet.

Pandion haliaëtus carolinensis. Osprey. Fish Hawk.

Rather uncommon and irregular in migration; not known

to breed in the County. Two adults were brought to Aiken in the autumn of 1912. Frequents both mountains and plains.

Aluco pratincola. Barn Owl.

The only record of this species for El Paso County is a specimen taken by Charles O'Connor, September 16, 1911, 14 miles easterly from Colorado Springs, which was secured for the College Collection.

Asio wilsonianus. Long-eared Owl.

Resident, quite common.

Asio flammeus. Short-eared Owl.

Winter visitor. Very common migrant, and many remain for the winter on the prairies. There is one in the Aiken Collection taken by E. P. Scheutze a few miles from Peyton, November 20, 1909. Two were seen at Ramah by Aiken, February 24, 1899.

Strix occidentalis occidentalis. Spotted Owl.

Rare. A specimen killed near Colorado Springs was brought to Aiken about 1875. Probably breeds as Aiken saw one alive in Deadman's Cañon, in June or July, 1873.

Cryptoglaux acadica acadica. Saw-whet Owl.

Winter visitor, rare. There are not many records of this little owl in El Paso County; Aiken has had several brought in to be mounted, and there is a mounted specimen in the Aiken Collection taken at Buttes, January 24, 1908. One was seen in April or May, 1902, at the corner of Cascade avenue and Kiowa Street, Colorado Springs.

Otus asio maxwelliæ. Rocky Mountain Screech Owl.

Winter resident; rare. But two or three typical birds have been taken in the County, but there are a good many

birds taken in winter which are lighter than typical *aikeni,* and which possibly may be a color phase or intergrades.

Otus asio aikeni. Aiken's Screech Owl.

Resident, common. Aiken has never found it anywhere except in cottonwood trees along the streams. It breeds commonly along Fountain Creek, and has been known to breed in Monument Valley Park. A pair bred in 1913 in a flicker's hole in a tree on St. Vrain Street, Colorado Springs, beside the home of Dr. W. W. Arnold, raising four young. The owls drove away the flickers which had bred in the hole the year before, taking possession for themselves. One was found dead in the vault of the cemetery at Colorado Springs, January 1, 1900.

Aiken once found the feathers of a Pink-sided Junco in the stomach of a Screech Owl which was killed in winter, but the species no doubt kills many more mice and such small mammals than it does birds, and is a very useful bird for that reason.

January 9, 1904, a Screech Owl in the red phase was taken near Colorado Springs, the skin of which is now in the Aiken Collection. This skin was examined by Mr. William Brewster, who pronounced it to be typical *Olus asio asio.* Later Mr. H. C. Oberholser also examined it, and considers it to be the red phase of *aikeni,* and tells us that he has seen several other specimens of the red phase of this subspecies, and that while very close to the red phase of typical *asio* they may be distinguished by being slightly paler in color. At the time of Mr. Brewster's examination this was the only red example of this subspecies known.

The following account of a pet Screech Owl may be of interest to our readers. The bird was captured after leaving its nest by a boy and brought to me alive and uninjured about June 25th, 1905. It was in the nestling or downy plumage,

the remiges nearly fully developed, and was able to fly. It was named "Jimmie," though subsequently ascertained to be a female, and became a great pet. It was allowed the freedom of the shop and the store, and later was allowed to fly out of doors evenings. She answered my call, alighted upon my wrist to be fed, and followed me about in the shop and out of doors. It began to moult about July 25th, and finished September 10 to 15, renewing all feathers except those of the wings and tail, which it did not shed.

Its baby or birdling call was like the smothered mew of a kitten; this was frequently uttered as a call for food or in answer to its name, or as a call to me for notice. After completing its moult this cry was not often uttered unless she was hungry and demanding attention. A note that was uttered when excited was a short *wow, wow,* repeated several times, reminding me of a puppy's bark. This was uttered at times when very hungry and demanding immediate notice, and was also uttered as notice of the presence of a dog—very vehemently when a dog came into the shop. A note like *cr-r-oo-oo-oo-oo-oo-oo* uttered gently and so low as to be heard only a few yards away was seemingly a love note and was an affectionate greeting to me as it would be to her mate. Then another note similar, possibly the same under other conditions was like the whistling of ducks' wings in overhead flight at night.

(C. E. A.)

Otus flammeolus. Flammulated Screech Owl.

Rare. The range of this species was extended to include Colorado by Aiken on his finding the bird and eggs June 15, 1875 in Copper Gulch, in southern Fremont County. But two specimens of this rare owl are recorded from El Paso County; one in nestling plumage was caught alive about the middle of September, 1883, on Fountain Creek at the mouth of Red Rock Cañon; the other was found dead along the same stream just

south of Colorado Springs, May 9, 1898. Both these birds were in cottonwood groves on edge of plains, but other records from the State are from the mountains from the foothills up to over 8,000 feet.

Bubo virginianus pallescens. Western Horned Owl.

Resident, common.

Horned Owls are common in El Paso County, more especially of course where there are trees, and range in the mountains as high as there is timber. It even finds its way into the city occasionally, for Lloyd Shaw saw one on North Nevada Avenue, Colorado Springs, June 1, 1911.

Nesting in hollow trees, using old Magpies' nests or building their own, and on ledges or in cavities in rocks or earth banks, the eggs are laid in March and the young hatched early in April. They are rather destructive birds and apt to attack poultry, though they also kill many mice, ground squirrels and gophers. April 10, 1899, one was brought to Aiken killed on the nest, which latter contained newly hatched young, and a rabbit and quail, the latter not torn or eaten.

Mr. Waldron, living at a ranch west of Pring, had a large number of domestic pigeons, which were preyed upon by the Horned Owls. One bird got into the habit of coming every day and killing a pigeon. Its method of attack was to swoop down on the birds as they rested on the roof of the barn and frighten them into flying. Then singling out some particular bird it would pursue that until it sought safety by returning to the barn, and the owl would so time its pursuit as to seize the pigeon just as it alighted, and carry it off.

Some years ago trout breeding was carried on at Manitou Park. It was discovered that something was taking fish from one of the ponds, and after some time it was found that Horned Owls were the culprits. Posts were set about the

pond, steel traps set on top of these, and several owls were captured. After that the fish ceased to disappear.

William Unruh, an old-timer who lived in the County many years ago, had a curious experience with a Horned Owl about 1875. He was camped in the mountains near Colorado Springs in the winter, and lounging by his campfire in the evening he made some movements of his head which caused his heavy beard to move about, and to his great surprise a Horned Owl suddenly pounced down upon his beard and seized it. Unruh grasped the bird by its legs and killed it, and brought it to town to Aiken.

There seem to be two forms of the Horned Owls in the County, a lighter colored bird which lives and breeds on the plains, following the streams a short distance into the mountains, living in the cottonwoods, and a darker bird which lives in the heavy timber of the mountains to timberline. While the female of these mountain birds is as large as the female of the plains form, the male is proportionately much smaller.

Bubo virginianus subarcticus. Arctic Horned Owl.

Rare winter visitor.

Four or five owls of this form have come into Aiken's hands during the past forty years. One submitted to Ridgway was referred to this subspecies.

Nyctea nyctea. Snowy Owl.

Winter visitor; rare. Two El Paso County specimens have been brought to Aiken, one killed somewhere on the Divide about 1875-77, the other near Ramah, about 1883. Besides these one was taken at or near Calhan in 1898, and one was described to him as killed on the Bates Ranch between March 20 and 28, 1899. Two years ago a man named Lightner spent part of the winter at the Half-Way House on the Pike's Peak Railway, and saw a Snowy Owl near there several times, though he did not shoot it.

Plate IX.

Fig. 16. *E. R. W., Photo.*
A Single Bird.

Fig. 17. *E. R. W., Photo.*
Desert Horned Lark.
A Flock feeding in Alamo Park, Colorado Springs, February, 1903.

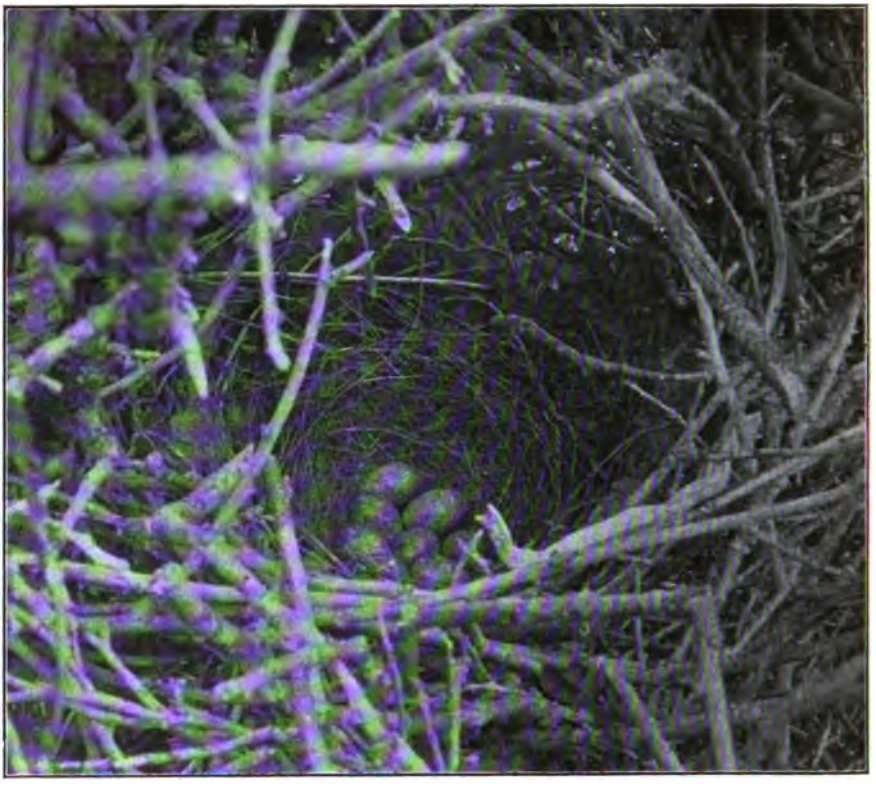

Fig. 18. *E. R. W., Photo.*
INTERIOR OF MAGPIE'S NEST, SHOWING EGGS.
Near Colorado Springs.

Fig. 19. *E. R. W., Photo.*
YOUNG MAGPIE JUST FROM NEST.
Gunnison County, Colo.

Speotyto cunicularia hypogea. Burrowing Owl. "Prairie Dog Owl."

Common locally about prairie dog towns. Apparently a summer resident only for it is not seen in winter, November 2, 1871, being the latest autumn date we have.

Burrowing Owls are not now as common in El Paso as they were formerly; too many are killed by hunters as they offer rather a tempting mark, and many are brought to the taxidermist to be mounted. It is a pity to slaughter the queer little fellows so uselessly and wantonly, for they are really of use when alive, feeding on mice and insects. They live in the deserted burrows of prairie dogs, laying their eggs several feet below the surface late in May.

As a table bird the Burrowing Owl is not to be recommended, Aiken says, and he should know, because he has tried it. Some years ago one was brought to be mounted on Saturday evening. The weather was warm and to keep the bird from spoiling until Monday Aiken carried it home and placed it in the family ice chest. Invited guests were present at Sunday dinner and when all were seated at the table Aiken's sister, who it may be stated is not as good an ornithologist as her brother, remarked that she had prepared a special dish for him —"the bird you put in the ice chest." At that moment the the waitress brought in a dainty looking browned and buttered fowl which from appearance might have been a woodcock, but it wasn't. A mild outburst of indignation passed and the laugh having subsided he generously offered to share his titbit with each one present, but each as graciously declined. Aiken, however, declared he would not allow the opportunity of testing the quality of owl meat to pass, so he cut a choice bit from the breast and ate it, after which he decided to save the balance of the bird for his dog. This dog was very greedy for meat. Anything in the way of meat offered he seized voraciously and gulped down. When this bird was held

temptingly toward him he seized it as usual but instead of swallowing it he very carefully laid it on the ground, took one cautious sniff of it and then dropped his tail and went into his kennel. No owls have been served at the Aiken table since that.

Glaucidium gnoma pinicola. Rocky Mountain Pygmy Owl.

Resident; probably more common than is generally supposed but often escapes notice from its habit of sitting quietly on a branch as a person passes by.

This little owl ranges to timberline, breeding from 8,000 feet up, having been known to nest at the Strickler Tunnel at almost 12,000 feet. It comes down to the plains in winter and at such times is not uncommon. It has been known to make its winter quarters in a barn on a ranch.

The bird seems to be of a perfectly fearless disposition, paying little heed to the presence of man, and often attacks birds larger than itself. William Unruh, in the winter of 1874-5, shot into a flock of Bohemian Waxwings on a dead pine tree and dropped several, when a Pygmy Owl which had been perching in the same tree flew down and seized one of the wounded birds as it reached the ground, and was shot by Unruh with the Waxwing in its claws.

Wallace Hook said that he was once walking through the edge of some timber in the mountains when he saw one of these owls dart after a flying Long-crested Jay, bearing it to the ground.

February 1, 1900, a Pygmy Owl was brought to Aiken which had been caught at the Garden Ranch near Colorado Springs under very peculiar circumstances. Two men were at the house on the ranch and heard the squalling of birds. They ran out to see what was going on and reaching the steep bank of the arroyo in which the creek there runs saw a Pygmy Owl and Bob-white Quail by the edge of the water. The owl

was on its back with the claws of both feet, clutched about the quail's neck, and the latter was fluttering and struggling trying to escape. The men jumped down into the gulch and picked up both birds, the owl offering no resistance, but by this time the quail was dead.

On the same date an employe at the Giddings Ranch, 12 miles east of Colorado Springs, told Aiken that he had seen Pygmy Owls attack half grown chickens in the farm yard, the method of attack being to swoop down from a nearby tree and strike the chicken in the head, and to follow this up by repeated passes until the chicken was disabled or exhausted. These various occurrences show it to be a day owl.

In 1884, a tie chopper working somewhere in the Ute Pass, near Green Mountain Falls, cut down a hollow tree in which were four young Pygmy Owls about two-thirds grown. One was killed by the fall, the other three were brought alive to Aiken, who kept them alive about two weeks. These birds were nearly fully feathered. When first taken in the hand they played possum, laying perfectly motionless, and it took a little time to induce them to sit up on a perch. While they were kept they made no cry nor any attempt to use their claws or to bite, exhibiting none of the ferocity with which adult birds attack their prey.

Geococcyx californianus. Road Runner. Chapparal Cock.

Resident; rare. This odd bird is a resident the year round, most of the records coming from along the Fountain Valley. It has also been reported from the sandstone hogback just north of the mouth of Bear Creek Cañon; from near Glen Eyrie, and has been seen several times on the mesa between there and Colorado Springs. Also reported from Austin Bluffs, Fountain, Bates Ranch, Barnes's Cañon, Turkey and Rock Creeks. There is a record from Palmer Lake. Where tree cactus grows it frequents the places where it is, elsewhere its is very apt to be found about oak brush.

Pike mentions in his Journal a bird about the identity of which there has been a certain amount of speculation, and which Coues considered to have been the Carolina Paroquet. The bird was taken by Pike December 25th, 1806, at which date he was camped, as estimated by Coues, somewhere about the neighborhood of Brown's Cañon, 7 miles above Salida. Pike says:

"Caught a bird of a new species, having made a trap for him. This bird was of a green color, almost the size of a quail, has a small tuft on its head like a pheasant, and was of the carnivorous species; it differed from any bird we ever saw in the United States. We kept him with us in a small wicker cage, feeding him on meat, until I left the interpreter on the Arkansaw, with whom I left it. We at one time took a companion of the same species and put them in the same cage, when the first resident never ceased attacking the stranger until he killed him."

Instead of being a Paroquet it seems much more probable that this bird was a Road Runner for various reasons. The color, green, applies to that bird as well as to the other, for many of its feathers are of that color, and there is a strong greenish tinge or cast to most of its plumage; the size of the body is just about that of a quail; and the feathers of the head are erectile and make a crest or tuft quite similar to that on the head of a Ruffed Grouse, which Pike probably meant when he compared it to a pheasant, that being the name by which the grouse was and is now known at his home. The fact that they fed the bird on meat is another point in favor of its being this species, which lives almost exclusively on animal food. It also seems that a Road Runner would be more likely to be caught in any trap Pike could have made than a Paroquet; moreover, Pike must surely have known what a parrot was like, and if he had caught one would have called it such, even though he might have expressed surprise at finding it in such a locality. Then again, if a Paroquet, the first caught

bird would hardly have been likely to have killed the other when put in its cage.

It may be objected that the altitude, above 7,000 feet, is too great for the Road Runner, but it must be remembered that there is a record of the bird on Marshall Pass, at 10,000 feet, not very many miles to the southwest, and the Arkansas Valley is here (Brown's Cañon), in spite of the altitude, a cedar and piñon region, in other words either Upper Sonoran or the very lowest portion of the Transition zone, and these zones are within the natural habitat of the bird, which is reported common fifty miles farther down the river.

To Aiken belongs the credit of having first advanced this theory as to the identity of Pike's bird, but it seems the most plausible to us both. Though somewhat beyond the limits of our paper the preceding note hardly seems out of place here, in view of the interest which is taken in Pike's travels in Colorado.

Coccyzus americanus americanus. Yellow-billed Cuckoo.

Summer resident; rare. Arrives the middle or last of May. There is a specimen of the Yellow-billed Cuckoo in the Aiken Collection, taken at Ramah, June 4, 1898, at which place two were seen. The bird seems to be very rare in El Paso County.

Ceryle alcyon. Belted Kingfisher.

Summer resident, not uncommon. A few remain through the winter. Considering that suitable localities for them are rather scarce in El Paso County, Kingfishers are not so very rare. They are noted frequently in the upper end of Monument Valley Park, where the small ponds contain suckers and such fish. One was noted there regularly in 1912 from July 28 to October 14, and in 1913 from April 10 to October 8. It was seen by Aiken during the winter of 1871-2.

Dryobates villosus monticola. Rocky Mountain Hairy Woodpecker.

Resident through the year; common.

Breeds from the foothills up to 10,000 feet or more, probably as high as there is suitable timber. Aiken took a nest with four eggs on Turkey Creek, May 26, 1872. Frequently seen in winter in the trees along the streams, and occasionally comes into the heart of Colorado Springs. It has been found at Lake Moraine in January.

Dryobates pubescens homorus. Batchelder's Woodpecker. Downy Woodpecker.

Resident; common, but somewhat irregular in winter; rare in summer. No breeding records known for the County.

This small woodpecker ranges over about the same area as the preceding species, but seems more irregular in occurrence and distribution. It has been seen at Lake Moraine in December, March, and June, and at Seven Lakes in January, showing that it is in those high altitudes the year round, while at the lower elevations it has been found at all seasons.

Picoides americanus dorsalis. Alpine Three-toed Woodpecker.

Rare resident in the mountains.

There are but few records for this species in El Paso County. W. C. Ferrill took one at Palmer Lake, June 4. 1900, which is now in the collection of the State Historical and Natural History Society at Denver. Dr. W. W. Arnold saw a pair breeding near the Half-Way House, June, 1905. Harry Amann killed one near Victor, Teller County.

In the summer of 1912, L. L. Shaw discovered a breeding pair in Crystal Park. The nest hole was in a dead aspen tree 8 inches in diameter, and was five feet above the ground.

There was but one young bird and that disappeared before it was ready to leave the nest, possibly captured by the Sharp-shinned Hawks which had a nest not far away.

Sphyrapicus varius nuchalis. Red-naped Sapsucker.

Summer resident; common. Arrives in April. Breeds in the mountains.

Sphyrapicus thyroideus. William's Sapsucker.

Summer resident; rather uncommon. Arrives early in April.

This woodpecker is a bird of the mountains, ranging from the foothills to above 10,000 feet. Aiken took a female in downy plumage on the Cheyenne Mountain road, August 29, 1897.

Melanerpes erythrocephalus. Red-headed Woodpecker.

Summer resident; common. Arrives the middle of May, departs in October, having been seen as late as the 25th.

This species breeds over the lower portions of the County especially in the cottonwoods along the streams, not going into the mountains in the nesting season, but after that time may wander quite extensively, and a young of the year was taken at Lake Moraine, September 2, 1905.

In 1913 a pair apparently took possession of a hole in Monument Valley Park which had been made and occupied by Flickers that spring, and they were there as late as May 13, but on the 26th the Red-heads had it. The Flickers were first seen at the hole the last of April. They could hardly have raised their young and presumably were forcibly evicted. The Red-heads were seen at the hole regularly after this into June, and on July 27 both old and young birds were seen near the nest site.

Asyndesmus lewisi. Lewis's Woodpecker.

Resident; common in summer, only occasionally seen in winter. The spring migrants arrive the middle or latter part of April, and the birds remain until the middle of November, at least at times.

While this species is noted above as a resident, it is much more abundant in summer than in winter, and very probably many winters none stay in the County. January 4, 1907, half a dozen or more were seen in the bluffs north of Colorado Springs, but this was a very mild winter. While it is found over most of the County where there are trees from about 8,000 feet down, yet probably in the breeding season most, if not all, are found in the yellow pines, though there are also some in the cottonwoods along the lower streams. It, however, leaves the pines to some extent when the young are fledged, and scatters over the County, and is sometimes seen in family parties on the plains at a considerable distance from the mountains. August 2 and 3, 1909, they were common in the Fountain Valley from the Pueblo County line north to Colorado Springs.

While on the Divide near Peyton in July, 1897, Aiken noted that this bird affected the tallest pine trees on the ridges and was continually taking flights from the top of one tree to another, often crossing ravines or going to a considerable distance and high in the air. They sometimes ascend vertically in the air 50 or 60 feet, perhaps to catch an insect, and then sail off to a tree top two or three hundred yards away.

Centurus carolinus. Red-bellied Woodpecker.

Rare; taken but once in El Paso County, by Aiken at Fountain, in 1873.

Colaptes cafer collaris. Red-shafted Flicker.

Resident; common..

Fig. 20. *E. R. W., Photo.*
YOUNG MAGPIES, THREE WEEKS OLD.
Gunnison County, Colo.

Fig. 21. *E. R. W., Photo.*
THE NEST IN THE TREE.

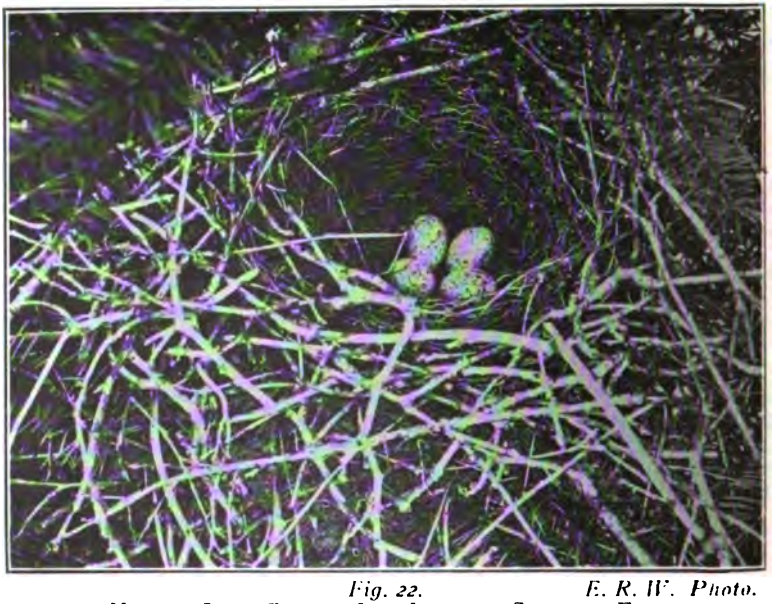

Fig. 22. *E. R. W. Photo.*
NEST OF LONG-CRESTED JAY, INTERIOR, SHOWING EGGS.
Near Bear Creek Cañon.

A common bird all over the County where there are trees, and ranging to timberline in the mountains, breeding throughout its range. Often seen in Colorado Springs through the year, in the summer devouring the ants on the lawns and gravel walks, and gathering grubs and insects. There are always some to be found in Monument Valley Park. As noted under the Red-headed Woodpecker a pair of Flickers had a nest there April 28, 1913, and were driven out by the other species. September tenth following a female Flicker was observed feeding young at this hole. A decidedly late date for a brood of this species to be coming out and it would be very interesting if one knew that it was the same pair which were ousted from that nest in May.

The majority of winter residents probably come from the far north, but it is certain that some individuals remain throughout the year. Dr. Arnold has fed the same pair throughout the year. Some of these winter birds have a well-marked red nape, and there is a series of specimens in Aiken's private collection which show every gradation from a mere indication of red on the nape up to a strong nuchal band a quarter of an inch or more wide. It would seem possible that these birds represent a distinct race.

They are distinct from the so-called "Hybrid Flickers," which are rarely seen either in winter or during the breeding season, but which are fairly common in migration, beginning to come in March, but rare in April; they return in September and October. These birds have the body coloration of *collaris*, and the red mustache, with the undersides of the wings and tail yellow or saffron. It is not uncommon to find breeding birds with a few yellow feathers in wing or tail. May 15, 1904, Aiken found at Ramah a Flicker's nest with seven fresh eggs, capturing the male bird on the nest. This bird had the underparts of the wing and tail bright salmon-colored. Some of our breeders with all red show a strong vinaceous

tinge on the breast, a tendency toward the northwest coast form *saturatior*.

The holes are usually excavated in dead wood, at almost any height from five to fifty feet or more from the ground.

O'Connor killed three Flickers with black cheek marks and yellow shafts about May 1, 1911, ten miles east of Fountain.

Phalænoptilus nuttalli nuttalli. Poor-will.

Summer resident; common. Arrives usually early in May, the earliest date being April 27, 1899, and departs late in September or early in October, having been noted on October 4th, 1904.

This species seems to be largely or entirely a bird of the foothills, and apparently at times ranges quite high, for Warren found young in the Sangre de Christo mountains, July 11, 1909, at an elevation of above 10,000 feet. It spends the day on the ground on the brush covered hillsides, flying out into the open spaces at dusk to hunt insects.

Chordeiles virginianus henryi. Western Nighthawk. "Bull Bat."

Summer resident; common. Arrives about May 23, departs usually by September 25.

The Nighthawk is common on the plains and the higher open ground, its habits being similar to those of the eastern bird, spending the day on the ground, on top of a post, or perched lengthwise on a limb or fence rail. The eggs, usually two, sometimes only one, are laid on the bare ground without the slightest semblance of a nest.

August 2, 1909, what appeared to be a migratory movement of Nighthawks was seen a few miles south of Buttes station; altogether from 50 to 100 of the birds were seen, all flying southerly in a leisurely manner and not hunting insects.

They were not in a flock, but came along in a scattering fashion, by ones, twos, threes or more.

August 4, 11 and 18, 1912, a Nighthawk was seen in Monument Valley Park, always on the same place on a certain limb or a cottonwood, presumably its regular roost during the day. The tree was on the bank of the creek, and not far from a walk which was quite constantly used. June 2, 1913, a Nighthawk was seen on the same high limb, probably the same bird returned for the summer. Because of absence from home no further observations were made until late in July, when nothing was seen of the bird, but during the summer men were working on the creek bank close by and no doubt disturbed the bird so that it abandoned the place.

Aëronautes melanoleucus. White-throated Swift.

Summer resident; locally common. Begin to come the last of March, Brewster and Allen having noted it March 24, 1882, but probably the main body comes early in April. Departs the middle or latter part of September, the 18th of that month being the latest date we have.

"Observed only at the Garden of the Gods, where many pairs were breeding, though sought for at Castle Rocks and other similar places. They breed in holes and crevices in the rocks, usually far above gunshot. They seemed very shy, and flew mostly near the tops of the highest rocks. Upon ascending the rocks most frequented by them they moved to other points, and thus managed to keep generally out of range. By spending a considerable part of two days, we procured only four specimens, though several others were killed, which fell in inaccessible places. They fly with great velocity and are very tenacious of life. As they swoop down to enter their nests, the rushing sound produced by their wings can be heard to a considerable distance. *Hirundo thallassina (i.e. T. t. lepida)* was also breeding here in similar situations." Allen, 1872.

The preceding description of the habits of this bird holds good today. It is, as would be inferred from this, a lover of cliffs and cañons, where it nests and raises its young in the most inaccessible places. Besides the Garden of the Gods, it is found about the Cheyenne Cañons, Bear Creek Cañon, and Sclater records it from Glen Eyrie. Lloyd Shaw noted it in Ute Pass and at the "Gateway Rocks" at Crystal Park, though not breeding there. June 5, 1909, the present authors saw tw or three near the Glen Cairn Ranch on Turkey Creek. Several were seen about the reservoir in Monument Valley Park, May 18, 1913. In May, 1908, Aiken observed a colony about two miles east from Palmer Lake, on the crest of the Divide, and saw some near St. Peter's Dome, in July, 1907.

Archilochus alexandri. Black-chinned Hummingbird.

Rare.

This species has previous to this only been recorded from the southwestern part of the State; however, Aiken saw a male hummingbird a short distance south of Colorado Springs May 17, 1898, which he believes was the Black-chinned. He also saw a female or immature hummingbird in Monument Valley Park August 18, 1907, which from the oscillating tail movement charactertistic* of this species he believes to have been the same. In July, 1906, a visiting lady bird student informed him that while sitting near the top of the Seven Falls in South Cheyenne Cañon a male hummer poised close before her which she positively identified as the Black-chinned.

*Aiken had exceptional opportunities of studying the characteristics of the four hummingbirds listed in the present paper while collecting in the White Mountains of Arizona in the summer of 1876, where all of them were plentiful. Following is an extract from his field notes: "*Rufus* most abundant species in August, frequenting open woods where extensive beds of scarlet pentstemon *(Pentstemon torreyi)* grow. Moults forepart of August without becoming ragged. Habit in common with *platycercus* of chasing others of species. . . . . These demonstrations accompanied by chippering notes, very loud for such small birds. Noise made by wings of *rufus* is a loud sharp hum approaching that made by *platycercus,* which is a whizzing noise that may be heard at a

Selasphorus platycercus. Broad-tailed Hummingbird.

Summer resident; common. Begins to arrive the first week in May. Departs in mid-September, the latest date we have being September 18, 1913.

This species is found all over the County, ranging well up into the mountains, being known to attain an altitude of above 10,000 feet, and breeding wherever found. In summer it often comes about the gardens in Colorado Springs, seeking its food from the flowers, and sometimes, when the leaves have fallen, and the birds have retired to their winter quarters, the delicate little nest will be noted on a shade tree by the street. One confiding bird built its nest on the electric light fixture directly before the front door of a house, on a porch where people were continually going and coming, and raised two young.

Selasphorus rufus. Rufus Hummingbird.

Summer resident; rare.

Aiken found this species on the Divide near Peyton in July, 1897, and noted one in Colorado Springs, August 21, 1898, and saw one near the mouth of Bear Creek, August 20, 1907.

One spring some fifteen years ago the mummified remains of a young Rufous Hummer were found in a barn at Manitou hanging to a piece of baling wire by the feet. It was supposed the bird went into the barn the autumn before, for

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distance of from 60 to 100 yards. *Alexandri* is less active, less aggressive. Noise by wings a plain hum. Female similar to female of *platycercus* but readily distinguished when hovering before a flower by the oscillating (up and down or backward and forward) movement of the spread tail. The other species carry the tail still. *Calliope* frequents same localities as the others but prefers different flowers. Keeps low in and among the plants where it easily escapes notice. Noise made by wings is a low hum like that of a large bumblebee. All four species have the common habit of alighting among trees, usually on a dead twig of a lower branch. They are very cute about hiding.

refuge from a cold storm, and perished from the cold, possibly freezing, and either thawed and dried out very gradually, or else that the toes were so much contracted that the feet did not lose their hold on the wire when the bird died.

Stellula calliope. Calliope Hummingbird.

Rare; but one record for the County, which was also the first for Colorado of the species. This was an adult male which was found dead in Cheyenne Cañon, July 25, 1897, by a Mrs. Martin, who brought it to Aiken. It was made into a skin and taken away by the finder.

Tyrannus tyrannus. Kingbird.

Summer resident; common. Arrives from the 5th to the 13th of May, and departs about September 7.

The Kingbird is common in the region in the summer, in the lower portions, ranging up onto the Divide. Its favorite breeding places are in the cottonwoods and other trees along the watercourses, and on the plains it nests wherever it can find suitable places. Keyser found a nest near Ramah containing four eggs, in the same tree with the nest of an Arkansas Kingbird and a Mourning Dove. He also found other nests about a mile away. Between Pueblo and Colorado Springs, August 2 and 3, 1909, it was seen frequently, but was not as common as the Arkansas Kingbird. The young are flying about the first week in July.

One August day an old bird was seen to feed its young grasshoppers in a Colorado Springs street, catching the insects on the ground in a vacant lot where they were plenty, and carrying them into the tree where the youngster was perched, beating them there on the branches, and then giving them to its baby.

At Ramah Aiken witnessed the attack of some Kingbirds on a Swainson's Hawk, which is described in his notes as

follows: "The hawk, which was sailing about the valley and screaming *scre-e* at intervals, came toward the line of trees fringing the creek, when three or four Kingbirds advanced to meet it. One of them flying down upon it from above alighted upon the hawk's head, and seizing the fathers of the forehead in its beak, straightened itself and pulled vigorously, and in this attitude was carried 40 or 50 yards through the air. The hawk made no effort to dislodge the Kingbird, neither did it show particular annoyance, though it turned presently and retreated in the direction from which it had come."

Tyrannus verticalis. Arkansas Kingbird.

Common summer resident. Arrives and departs at about the same time as the preceding species.

The Arkansas Kingbird is the most common of the three species found in the County and is found through much of the territory treated in this list. Between Pueblo and Colorado Springs, August 2 and 3, 1909, it was very common, and family groups were frequently seen. In 1898, Aiken found breeding near Ramah, in a quite limited area, about fifty pairs of Arkansas Kingbirds, and only about eight pairs of Cassin's. As noted under *T. tyrannus* Keyser found it breeding near Ramah, and a nest he found contained three young and one egg. Aiken found a nest there with eggs June 5, 1898, also a number of freshly built nests which did not yet contain eggs, showing that the nesting season was hardly in full swing. This species is not altogether dependent upon trees for nesting sites, for nests have been found in cavities in stream banks, between two fence posts, and under the rafters of a log cabin; possibly the other species may use similar sites, but we have not happened to notice such. In July, 1907, Aiken saw a nest of this species upon the crossbar of a telegraph pole at the Buttes station of the Santa Fe R. R., and the agent told him the birds had nested on the same pole the previous year; he said they were a great protection to his poultry, attacking and driving away every hawk which came in sight.

Tyrannus vociferans. Cassin's Kingbird.

Summer resident; not common. Arrives and departs at about the same times as the two preceding species.

Cassin's Kingbird is not nearly as common as the preceding species, being the least common of our three Kingbirds, and thus its distribution through the County is not quite so well known, though it inhabits the same localities. Its comparative abundance with the Arkansas at Ramah has already been mentioned under that species. Lloyd Shaw noted a pair breeding near Prospect Lake, June 1, 1911.

Aiken's notes compare the habits of this and the preceding species as follows:

"Although the two species resemble one another so closely in appearance there is much difference in the manners and actions of the Cassin's and Arkansas Kingbirds. The Arkansas Kingbird comes out to meet the intruder and hovers about in the air, chattering continually; they hover about the top of a tree and alight upon the topmost twigs. Cassin's Kingbird is more sedate, less active, and less noisy, and has less of the fluttering motions. It alights usually upon the side branch of a tree or in the body of it, and often sits quietly, though usually their call note, *cu-ver-o,* is uttered at intervals of four or five seconds in a harsh tone."

Myiarchus cinerascens. Ash-throated Flycatcher.

The only record we have of this species for El Paso County is a specimen taken by Aiken May 21, 1872, near Red Creek Cañon, close to the Fremont County line, several other being seen at that same time. It frequents piñon and cedar regions, and probably is not uncommon in that portion of the County as a summer resident. One was seen by Warren June 6, 1909, at Glendale, in Fremont County, but only a few miles southwest of the above-mentioned locality.

Plate XIII.

Fig. 23. *E. R. W., Photo.*
ROCKY MOUNTAIN JAY OR CAMP BIRD.
Gunnison County, Colo.

Fig. 24. *E. R. W., Photo*
CLARKE'S NUTCRACKER.
Gunnison County, Colo.

Fig. 25. *E. R. W., Photo.*
NEST AND EGGS OF DESERT HORNED LARK.
Near Colorado Springs.

Fig. 26. *E. R. W., Photo.*
NEST AND EGGS OF WESTERN MEADOWLARK.
Weld County, Colo.

Sayornis sayus. Say's Phœbe.

Summer resident; common. Arrives about April first, and departs the last week in September. The earliest date of arrival being March 15, 1914, and the latest date at which it has been noted being September 28, 1913.

Say's Phœbe is a common summer resident in the County, ranging quite high at times, having been seen at Lake Moraine, September 2, 1905, and June 17, 1900, found breeding at Divide station, Teller County, 9,200 feet. Its breeding habits are quite similar to those of the Eastern Phœbe, for it likes to nest on the sills and joists of buildings about ranches and farms, under bridges and similar locations, in cavities in stream banks, under rock ledges, and even down in wells in the stone curbing.

June 21, 1905, three young, able to fly, were seen with their parents about a house, and the old birds were feeding them. That their appetites were good was shown by their swallowing *Pyrameis* butterflies whole. They are indefatigable insect catchers, and continually in pursuit of prey, and the number of insects annually consumed by one must be enormous. It has the habit of perching on trees, posts, fences, or tall weeds, and continually uttering its calls, something like that of the Eastern Phœbe.

Nuttallornis borealis. Olive-sided Flycatcher.

Summer resident in the mountains; not uncommon. Arrives May 20-25.

A large, rather heavily built flycatcher, with large bill, easily recognized in its summer home by its habit of perching on the topmost branches of dead trees, whence it makes its flights in pursuit of insect prey. It breeds exclusively in the mountains, going nearly to timberline. July 4, 1907, Aiken found five or six pairs breeding on the hillside below St. Peter's Dome station. It was common in Crystal Park, August

first, 1912. Several were seen about Monument Valley Park May 26 and 27, 1913; this was of course just after their arrival in the spring.

Myiochanes richardsoni richardsoni. Western Wood Pee-wee.

Summer resident; common. Arrives about May 20, departs the last of September.

Found practically all over the County wherever trees can be found, whether on the plains or in the mountains. It was common on the Divide north of Peyton July 17, 1897, 15 being seen then. Aiken noted them singing as late as August 25, the song being *zee-a,* uttered in an explosive manner.

Empidonax difficilis difficilis. Western Flycatcher.

Summer resident; not common.

Most common in the mountains, and it is rarely found along the Fountain during the spring migration. Its habits are similar to those of other flycatchers of the genus. Noted on the Divide north of Peyton, August 28, 1907.

Empidonax trailli trailli. Traill's Flycatcher.

Summer resident; common. Arrives about May 25.

Common almost everywhere in the County, up to nearly 9,000 feet. Seems to prefer the neighborhood of the alders along the creeks.

Empidonax minimus. Least Flycatcher.

Rare migrant; arrives in May.

This widely distributed Eastern species reaches the western limit of it range at the eastern base of the Rocky mountains. It was first taken in Colorado by Aiken on Turkey Creek, May, 1873, and in recent years he has found it several times along Fountain Creek between the towns of Fountain

and Colorado Springs (May 13 to June 6), and at several points along the line of the Rock Island Railroad eastward. Warren has noted one in Monument Valley Park. The earliest dates of arrival are those of Allen and Brewster, who have recorded two specimens taken May 4 and 9, respectively, during their visit to Colorado Springs in 1882.

The Least Flycatcher may be looked for among the scattered cottonwoods that fringe the streams issuing from the foothills, or which mark the occasional waterholes on the plains eastward toward the Kansas state line. It has not been found in the mountains and is not known to breed south of Wyoming. A specimen taken by Aiken in the pine belt on the Divide north of Peyton August 28, 1907, is the first record of its capture at so high an altitude as 7,000 feet or among conifers; also the only autumnal record

Empidonax hammondi. Hammond's Flycatcher.

Summer resident; rare. Arrives in May.

The eastern range of Hammond's Flycatcher meets the western range of the Least Flycatcher along the eastern base of the mountains, and except in favored localities it is scarcely more common. A specimen taken by Aiken May 20, 1908, at Butte Station on Fountain Creek is the most eastern reported in the County. The distance from the foothills is about 12 miles. Aiken met with it several times in the early seventies along Turkey Creek within the foothills, but it was somewhat more common on Beaver Creek, which runs through a narrow valley between piñon clad hills in Fremont County just west of our County line. Allen and Brewster took it in 1882. All migrants pass further north or retire to higher elevations to breed.

Our opportunities for observation in the mountains have not been extended enough to enable us to speak with much assurance as to its nesting within the County, but we have no

doubt it does, Aiken found a small *Empidenax* in a willow thicket on the south slope of Pikes Peak, July 9-10, 1899, believed to be of this species, which, however, he failed to secure.

Empidonax wrighti. Wright's Flycatcher.

Summer resident; rather common in migration. Arrives in May and has been taken as early as the sixth (1899).

This species breeds in the mountains, probably to or nearly to timberline. The nest, as found by Warren in Gunnison County, is a cup-shaped structure made largely from the shredded inner bark from dead aspens built in the crotch of a willow. The eggs are usually four in number and pure white

Empidonax griseus. Gray Flycatcher.

A single record for El Paso County, a bird taken by Aiken at Fountain, May 3, 1872.

Otocoris alpestris leucolæma. Desert Horned Lark.

A common resident.

The Horned Larks are found on the plains and in the open country west from Green Mountain Falls. In other parts of the State they are also found above timberline in summer, breeding there, but we do not have any records of this sort for El Paso County. While the birds are residents, it is most likely that their numbers are augmented in winter by migrants from farther north, and quite possible that some of our summer residents may go south. Beginning to breed, as it does, in early April, it raises at least two broods in a season, and young have been seen being fed by their parents the last of June. A nest with three eggs was found near Colorado Springs May 14, 1903; the parent was incubating then. This nest was, as always with this species, on the ground, almost flush with the surface, and sheltered by a tuft of grass. Allen and Brewster mention a nest with two fresh eggs April 1, 1882, and full-fledged young seen April 22 and later. September 8, 1904,

a young lark was seen which could not have been long out of the nest.

While the larks usually remain on the plains during the winter and are not especially conspicuous by their numbers, yet when severe weather comes, especially if it is accompanied by snow which lays some length of time without melting, making it difficult for the birds to obtain food, they will come into town, sometimes by thousands. This has been the case in several different winters. The winter of 1902-3 was quite a notable instance of the sort. It was a very cold winter, with snow on the ground much of the time, and consequently the larks could find little or no food on the plains, being unable to reach the ground under the snow. This being the case, they were in Colorado Springs in great numbers. The people were feeding them in many places, putting out millet and similar food for them. One feeding place was near the County Courthouse in Alamo Park. A space 8 by 12 feet would be covered by the birds feeding, and also at other feeding places they would alight so thickly as to hide the ground. February was the most severe month; after March first the weather moderated and the birds began to disappear from the town. May 14, 1912, during a cold storm with snow, Horned Larks were driven into Colorado Springs as far south as Weber and Columbia Streets. For some reason none came into the town in February, 1913, though there was snow on the ground for several days.

During these cold winters there is great mortality among these birds, many perishing from cold or hunger. Many are found dead under wire fences, and it would seem possible that the birds light on the wires with their feet wet from being in the snow, and the toes freezing to the wires the birds cannot get away and so freeze to death there, and afterward fall to the ground when the feet relax their hold from thawing.

Taking advantage of the opportunity afforded by the finding of large numbers of Horned Larks dead at times of storms

Aiken has carefully examined large series of such birds to observe the range of individual variation and to discover if extralimital forms occur. January 30, 1898, with 120 specimens in hand he writes: "I detect only one form, *leucolæma,* and the differences are doubtless due to age and individual variation. The majority of males measure 7.25 inches in length, wing 4.23. The brightest colored are nearly as bright as breeding birds and are assumed to be oldest, though some with pale throats appear full adults. The yellowest throated birds have this color suffusing the entire chin, throat, and sides of neck, and tinging the frontal and superciliary stripes. No males are found with immaculate white throats, but many have a narrow whitish streak from chin to breast-collar.

Streaked upper parts are taken to characterize immaturity, but some marked thus have yellow throats and some with paler backs have pale throats. It appears, therefore, that intensity of yellow is not due to age, but to individual variation. The same variation exists among breeding birds. An undoubted immature plumage is seen with duller pinkish colors and undeveloped black loral and breast markings like females.

Females average considerably smaller. The brightest have the yellow suffusion nearly as intense as in the brightest males, but many females have white throats with no trace of yellow."

Aiken has also ascertained that breeding birds at high altitudes in the mountains do not differ from those breeding on the lower plains. Only one specimen has been detected that approaches the Mississippi Valley form; this has been pronounced by Mr. Oberholser as intermediate between *leucolæma* and *praticola.*

Pica pica hudsonia. Magpie.

Resident; common.

The Magpie is possibly the most noticeable bird, at least to strangers, in the whole Pikes Peak region. With its conspicuous black and white plumage and long tail it at once attracts the attention of the tenderfoot, and the old-timer generally notices one when it appears. Found wherever there are trees, it lives along the watercourses and through the mountains, though avoiding the dense evergreen timber, and probably not breeding much above 9,000 feet, but it is reported to occasionally visit the summit of Pikes Peak in summer.

The bulky nests are built in almost any sort of tree. though deciduous growth seems to be preferred, but conifierous trees are occasionally used. They are placed anywhere from 3 to 50 or more feet above the ground, and we find them in the willows along the streams, in the scrub oaks of the foothills, and up toward the tops of the tall cottonwoods. The nests are quite remarkable structures; built with a foundation of twigs in which is a deep cup of mud lined with fine roots and similar material, and over all is a dome or roof of twigs and small branches, with the entrance hole in one side, just above the edge of the cup. In this are laid the eggs, as many as thirteen having been found in one nest in Montana; from six to eight is the usual number. The eggs are laid, in the vicinity of Colorado Springs, the latter part of April, five were found April 24, 1913, and there are other equally early dates, while fresh eggs are likely to be found all through May. The following dates give an idea of the laying season: May 3, 1904, a nest with one egg was found, and when next visited, the 16th, there were 8; May 10, 1904, several eggs were found in a nest so situated it was difficult to count them; May 11, 1904, nest with 2 eggs; April 25, 1910, 5 eggs; April 24, 1898, 4 eggs. The young come out of the nest about a month after hatching, but can fly only a little then or not at all, and merely hop around in the branches of the home tree or bush, and are cared for by the parents for two or three weeks longer, perhaps more. Shaw found a nest with 4 young about 3 weeks old, June 25, 1912, in Crystal Park, at 8,500 feet.

After the breeding season is over and the young can fly well the Magpies scatter about everywhere, and especially in winter are they widely distributed seeking food. They are seen at Lake Moraine all through the winter, though they do not appear to breed there, as no nests were noted in that vicinity. In the fall there also seems to be a southward migratory movement of the species, as they are seen in large numbers along the Fountain Valley moving in a southerly direction.

One day late in September, 1913, three or four Magpies were seen near Monument Valley Park mobbing a couple of Sharp-shinned Hawks, flying at them and annoying them in every way possible.

Cyanocitta cristata. Blue Jay.

An accidental visitor, only one instance being known of its occurrence in El Paso County, a bird seen in Colorado Springs October 5, 1902, by E. P. Scheutze. Aiken took one May 27, 1905 near Limon, about 20 miles northeasterly from the northeast corner of the County. Blue Jays are abundant in western Kansas almost to the Colorado line, and also at Wray, in northeastern Colorado, and with the settlement of the intervening region an overflow through our State within a few years may be looked for. Aiken found them at Goodland, Kansas, and over the country east of there in May, 1899. They were observed in flocks flying from one tree claim to another, which were in most cases several miles apart.

Cyanocitta stelleri diademata. Long-crested Jay.

Common resident in the foothills and mountains and on the Divide.

The Long-crested Jay, or "Blue Jay," as it is usually commonly called about here, is nearly as familiar a bird about the foothills and cañons as the Magpie, as it flits among the trees and bushes, sociable but shy, and it calls forth many exclamations of admiration from the tourists because of its

Fig. 27. *E. R. W., Photo.*
MALE BREWER'S BLACKBIRD.
Colorado Springs.

Fig. 28. *E. R. W., Photo.*
WESTERN EVENING GROSBEAK.
Colorado Springs.

Plate XVI.

Fig. 29. *E. R. W., Photo.*
WESTERN VESPER SPARROW.
Colorado Springs.

Fig. 30. *E. R. W., Photo.*
WESTERN LARK SPARROW.
Colorado Springs.

handsome plumage. Its range in winter is similar to that of the Magpie, from the plains to high into the mountains, up to Lake Moraine and Seven Lakes, 11,000 feet, but its breeding range is much more limited, being between 6,500 and 8,000 feet.

Its food consists of almost anything eatable, seeds, grain, insects, nuts, etc. A pair killed near St. Peter's Dome by Aiken, June 13, 1907, had been after food for their young. Each had its mouth full of food, and had used discretion in gathering it. They had been first to the garbage pile of the station, and filled the throat with soft bread, after which they had caught several winged ants, grasshoppers and spiders that were held by the bill, extending along the length of the mandibles.

A nest was found by Warren in a gulch near Bear Creek Cañon, May 5, 1913, containing then 3 eggs, and there were 4 May 8, when the nest was collected, and which is now in the Colorado College Museum. The nest was 6 feet from the ground in a Douglas's fir sapling, only 2 inches in diameter at the base, and on a branch close to the stem of the tree. The outside diameter of the nest was about 10 inches, and it was 5 deep, the nest cavity being 4½ inches in diameter inside, by 3 deep. The outer portion was a loosely constructed affair of twigs, varying from ⅛ to ¼ inch thick, while the inner portion was of fine rootlets closely put together, and with the walls of the cup varying from ½ to ¾ inch in thickness. The structure was loosely laid on the few branches which supported it, looking as if it might easily fall off.

This species differs in habits from the Eastern Blue Jay, being less noisy, and not going in flocks in fall and winter, though parties of half a dozen or more are seen at times.

Aphelocoma woodhousei. Woodhouse's Jay.

Resident; rather common from the edge of the plains up to 7,000 feet.

Woodhouse's Jay is a bird of the foothills, being found in the scrub oak brush along the base of the mountains, and the lower parts of the cañons, but not going to any great elevation; it is also found about Austin's Bluffs. Occasionally in winter it comes into town; from November 20, 1910, to April 16, 1911, at least four were about the north end of Monument Valley Park and vicinity and were frequently seen about houses four or five blocks east of the Park.

Aiken found two nests May 2, 1872, and his description was the first to be published of the nesting of the species. The nests contained 4 and 5 eggs respectively. His description is as follows: "Nest composed outwardly of dead twigs, then of fine roots, and lined with fine rootlets and horsehair. The eggs, four or five in number, are laid about May 1st. They are of a light bluish-green color, with the reddish-brown specks thickest at the large end."

When Aiken was at his ranch on Turkey Creek in October, 1873, a migratory flight of Woodhouse's Jays was seen. They were not flying high, but making short flights from point to point, always in a southerly direction. It was estimated that there were at least 500 scattered over from 50 to 100 acres of ground, as they kept lighting after their short flights. After this flight had passed the species seemed to be fully as common during the following winter as it had been during the summer. The flight had undoubtedly come from a more northern locality. Local birds appear to be non-migratory and are found in the same localities throughout the year.

Perisoreus canadensis capitalis. Rocky Mountain Jay. Camp Bird. Camp Robber.

A not uncommon resident of the higher elevations, from above 10,000 feet to timberline.

This species is a bird of the Hudsonian zone, where it spends most of its life, breeding in the heavy timber very early in the spring. Occasionally in fall and early winter it

wanders lower down, and has even been seen in the streets of Colorado Springs. It comes about the houses of the care takers of the Colorado Springs water system in the mountains, at 10,000-11,000 feet, to pick up what scraps may be thrown out, and at times becomes very tame and familiar. It is quite easy to induce them to take food from one's fingers. They carry off more than they eat, presumably hiding and storing it for future use.

Corvus corax sinuatus. Raven.

Resident.

A few pairs of Ravens are resident on Pike's Peak about timberline, where it is said they are increasing in numbers and are supposed to breed in the "Crater." They are seen occasionally by occupants of the house on the summit and one was killed there by J. G. Hiestand in the autumn of 1912. It has been noticed near Seven Lakes in January and on Bison Creek, near Clyde, in September. In winter they may descend to the plains at rare intervals, probably less often than 40 years ago. Several reports of a "crow" or "raven" seen have come to Aiken within the past few years, but the descriptions were not sufficiently accurate to make identification positive. One was caught in a trap and brought to Aiken in 1901, and Dr. W. W. Arnold kept one as a pet for two or three years which had been brought to him with a broken wing.

Corvus cryptoleucus. White-necked Raven.

Formerly a common resident, now unknown in the County.

The following quotation from Henshaw's Report on the Ornithology of the Wheeler Surveys published in 1875, gives an account of its former occurrence and habits:

Mr. Aiken communicates the following:

"It seems to me not a little singular that I should have been the first to detect the presence of this bird in Colorado,

for it outnumbers all the other *Corvi* in certain localities. It had previously been considered a bird of the southeast, and was supposed to be confined mainly to the Staked Plains of Texas, but I now know it to be common along the eastern base of the Rocky Mountains, throughout the entire extent of Colorado, and it even winters as far north as Cheyenne. It has also been found at Tucson, Ariz., by Capt. Bendire, who includes it among the resident birds of that locality, so that it has quite an extended range. I first saw them in October, 1871, about twenty-five miles south of Cheyenne, on the line of the Denver Pacific Railroad, where a large flock was hovering over the plain. In the city of Denver I have often found them searching for food in the less frequented streets, and about one hundred miles farther south, on the Fontaine Qui Bouille, I have seen immense numbers. At the latter place, a flock of probably one thousand individuals was resident during the winter of 1871-2. Although so abundant in winter, very few are to be seen in summer; the greater number either pass to the northward or become so distributed over the country as not to attract attention. Being seldom disturbed, these birds have little of the shyness which the common crow of the East exhibits, though it is not always easy to get within gunshot of them. I have on one occasion ridden along within twenty feet of a fence on which sat thirteen of these 'imps of darkness,' only one of which flew away, the others contenting themselves by keeping a watchful eye on my demeanor, and an instant's halt on my part, or a suspicious motion, would have started them off instantly. *C. cryptoleucus* is mainly a bird of the plains, being replaced in the mountains by the common raven. The two birds resemble each other so closely in notes and habits that it is difficult to distinguish between them at a distance; the greatest apparent discrepancy being in size, though the croak of *carnivorus* (i. e. *sinuatus*) is somewhat deeper and louder than that of the other. I have sometimes found them both associated in the same flock. Each succeeding year since I first saw these birds I have noticed

a marked decrease in their numbers in El Paso County, Colo. The cause of this I do not know unless it is because as the country becomes more thickly settled the solitude they love so well is denied them." Pp. 326-7.

Since the above was written Aiken has changed his opinion as to the cause of the disappearance of the White-necked Raven from this region. Some strong incentive was necessary to have induced these birds to wander northward from their native range in western Texas and New Mexico. This was offered by the slaughter and extermination of the buffalo herds on the western plains which was going on during the late sixties and early seventies. Pioneer settlers were pushing ahead of the railroads; transportation was by teams, and travelers camped along the roads and fed grain to their stock. The Ravens, probably first attracted by the buffalo carcasses that strewed the northern plains later followed along the routes of team travel and fed on scattered grain left by campers. By 1874 the buffalo were nearly gone; completed railroads had put the wagon freighters out of business; frequent houses along most roads provided shelter for travelers and camping became unnecessary; the food supply of the White-necked Raven was curtailed and the bird presently retired to its former habitat.

An unusual record for altitude is California Gulch, August 27, 1872 (Aiken).

May 17, 1878, Aiken found on Horse Creek, some sixty miles east of Colorado Springs, in what is now Lincoln County, a nest of the White-necked Raven which contained 7 nearly hatched eggs. Of two other nests of the same species found five days later, one contained 5 half-grown young, and the other 6 (traces of a 7th having been broken) nearly fresh eggs. Nest cup-shaped, inside of hair and wool firmly matted and woven and outwardly built of dry twigs.

Corvus brachyrhynchos. Crow.

Rare. The Crow has been taken so infrequently in El Paso County that it would seem to be nothing more than a straggler. There are but two specimens in the Aiken Collection, one without date, taken near Colorado Springs, the other from Monument, taken in November, 1906. It is strange it should be so rare here when there are many places north of the Divide where it is a common bird. This species was common 15 miles southeast of Colorado Springs in February and March, 1914, where they they were feeding on carcasses of sheep killed by heavy snowstorms.

Nucifraga columbiana. Clarke's Nutcracker. Clarke's Crow.

Not uncommon resident in the mountains, coming lower down in winter.

Like the Rocky Mountain Jay, by whose names of Camp Bird and Camp Robber it is sometimes called, Clarke's Nutcracker is a bird of the higher mountains, breeding quite early in the green pine and spruce timber. There is a full grown young of the year in the Aiken Collection, taken at St. Peter's Dome, June 21, 1907. It is rather more of a wanderer than the other species, and habitually comes down to lower elevations in winter and the early fall than that species does, Wetmore and Rockwell noting a number at Palmer Lake September 6, 1909. It is plentiful in the Turkey Creek valley in autumn. It has been seen at Lake Moraine in March, June and September, and at Seven Lakes in January. In winter it is found about the foothills and at Austin's Bluffs, and probably wanders and straggles over most of the region where there are trees. In September and October this species is apt to be found among the piñons, living on the seeds or nuts of that tree, getting them sometimes by clinging to a cone and hanging upside down from it and extracting the seeds from below, and again standing on top of a cone and reaching over and

picking out the seeds from above. A pair noticed on the summit of Cheyenne Mountain in May, 1913, by Aiken, are thought to have bred there.

Cyanocephalus cyanocephalus. Piñon Jay.

Resident; common locally.

The Piñon Jays breed in the piñons and cedars, of which there are but a comparatively small area in the County, laying its eggs so early in the season that the young are out of the nest by the first of May. Late in the summer and early in the autumn they begin to wander about in flocks, often of many individuals, reaching both higher and lower elevations than their breeding range. Wetmore and Rockwell saw it at Palmer Lake September 6, and Warren saw one on Bison Creek, near Clyde, at 10,000 feet, September 8, 1911; extremely high for this species. In winter it is now common at Austin's Bluffs, near Colorado Springs, but thirty years ago it was very rare there or not seen at all. The reason for this change may be that in the early days there was no food for them about there, and now there is considerable farming with corn and grainfields where food may be found. Occasionally flocks may be seen flying over the city of Colorado Springs on their way back and forth from their feeding grounds.

Dolichonyx oryzivorus. Bobolink.

Rare spring and summer visitor; no breeding records.

Allen and Brewster state that "A single specimen was brought to Mr. Aiken May 18, [1882], and another May 23; two others reported as seen. But two specimens were previously known to Mr. Aiken as having been killed here."

There is a male in the Aiken Collection taken near Colorado Springs, September 5, 1897. May 20, 1913, Warren saw two males in Monument Valley Park, and one on the 21st and 22nd.

Molothrus ater. Cowbird.

Summer resident; common. Arrives about the last of April. Departs in October, has been seen as late as the 29th.

The Cowbird, well known for its habit of laying its eggs in the nests of other birds, is a rather common summer resident in much of the County. Bendire, in his "Life Histories of North American Birds," figures a Cowbird's egg taken from the nest of a Mountain Song Sparrow in El Paso County by Aiken, and Aiken took two eggs from a Meadowlark's nest near Ramah, June 4th.

Xanthocephalus xanthocephalus. Yellow-headed Blackbird.

Summer resident; common in suitable localities. Arrives the last of April, and departs in September.

Localities such as the Yellow-headed Blackbird prefers for breeding places are rather rare in El Paso County, for swamps and sloughs with plenty of tules and rushes are their favored resorts, and there are not many such within our limits, Skinner's being the only place where we know of its breeding within the County. The nest is woven to the stems of the tules, and forms a rather deep cup in which 4 or 5 eggs are deposited.

Agelaius phoeniceus fortis. Thick-billed Redwing.

Resident; common.

While the Red-winged Blackbird may be considered a resident species as some individuals remain through the winter, yet it is more abundant in the summer, the migrating birds coming in the spring about the first of March, or the last of February, the males always preceding their mates. Probably most, if not not all, the winter birds are a different lot from the summer residents. They are found all over the County, at least below the foothills, where there is such ground as they like, for they are always found near water, and breed throughout their range.

Plate XVII.

Fig. 31. *E. R. W., Photo.*
WESTERN TREE SPARROW.
Colorado Springs.

Fig. 32. *E. R. W., Photo.*
INTERMEDIATE JUNCO.
(In a photograph Shufeldt's Junco would look very like this).
Colorado Springs.

Fig. 33. *E. R. W., Photo.*
PINK-SIDED JUNCO.
Colorado Springs.

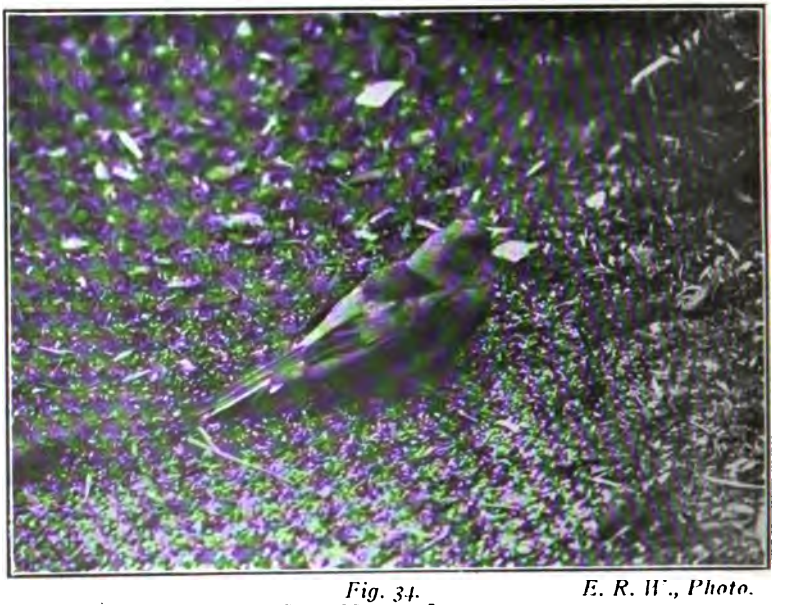

Fig. 34. *E. R. W., Photo.*
GRAY-HEADED JUNCO.
Gunnison County, Colo.

All the Redwings in the Aiken and Warren Collections have recently been examined and identified by Mr. H. C. Oberholser of the Biological Survey. These included 22 specimens from the region now under consideration, taken at various dates through the year from January 24 to November 20, and all were labeled by Mr. Oberholser as *A. p. fortis.*

Sturnella neglecta. Western Meadowlark.

Summer resident; common; a few often spending the winter. Arrives early in March, sometimes the last of February. Departs late in October or early in November.

One feels as if spring had really come when he hears the Meadowlarks singing from the light and telephone poles in town, and the fence posts along the roadside, for they are no sooner here than they announce themselves with their cheery notes. Found everywhere on the plains region, and in the lower portions of the mountains where there are open spaces, it is one of our commonest species, and most useful as well, living very largely on insects of all sorts, of which it destroys vast numbers in a season.

Two broods are raised, sometimes at least. In the summer of 1903 a pair nested and raised two sets of young in a vacant lot at the corner of Cascade Avenue and Caramillo St., in Colorado Springs, with houses all about them. September 8, 1904, a young bird hardly able to fly was seen on the outskirts of the town. The nest is built on the ground, usually well hidden in long grass, often with more or less of a dome-shaped roof of grass above it. The eggs vary from four to six. June 4, 1909, a nest with one egg and one young bird several days old was by the Cañon City road several miles southwesterly from Colorado Springs.

The song of the Western Meadowlark has been the theme of many writers, its beauty and variety arousing the admiration of all who hear it. Mrs. Sturgis has lately published a little book with words and notes of a number of songs as heard

about Colorado Springs; Keyser could hardly find words to express his admiration and wonder of the lark's music, and others have written in the same strain.

June 4-7, 1898, Aiken made notes on Meadowlark songs at Ramah, as follows:

"The variety of its song is quite remarkable. I noticed some styles of song different from those in the vicinity of Colorado Springs, and some that are the same. It is a common thing to hear a certain lark that has been singing one song for a time change to another in different key, and with different notes and inflections. I take it that each bird has two songs. Two by one individual which I noted were: *see, ching-ling, chick-le-pup,* and *see-saw, chick-a-lit-tle, chick-a-loop.* The song consists usually of seven or nine notes or syllables, a combination of clear flute or whistling notes with liquid and guttural tones. Usually one or two notes receive special emphasis, and the variation of accent is one point of difference. It is often on the last note but is also given on various notes in the song. The different key in which different songs begin and end is another point, but the notes themselves differ widely in different individuals. The following songs are most often heard at Colorado Springs, and also at Ramah: *See-saw-see, bil-lee-co-bah; co-que-co, queed-lick, tweè-pah; bah beèp-a-lo, chuck-a-luck.* In the last the first part is the conspicuous part, but in the two others the last part is most pronounced. I also note at Ramah the following: *ta ti ta ta, ta-ty-ta,* the second note on a higher key, and the last three uttered like tremolo; *eè too, eat a little ee-tle doo-ple.*" Subsequently to writing this Aiken heard five of the familiar songs uttered by one bird within a few minutes.

In June, 1900, he made the following note on the song of a lark at Hartsel, Park County: "I heard a song I had never heard before, 'Come Wil-lie, come quickly home.' I had almost concluded the mountain larks had songs unlike

those of the plains, when the same bird sung one of the most familiar ones."

Icterus bullocki. Bullock's Oriole.

Summer resident; common. Arrives about May 10. Most of them leave the latter part of August; the latest date at hand is September 14, 1903.

Orioles are found all over the County wherever there are trees, below 8,000 feet. When the leaves are gone from the trees in autumn many of their pensile nests are seen hanging from the extremities of the branches, testifying to the abundance of the builders. Practically all the nests are built in the cottonwood trees, these being the most suitable kind we have for their style of architecture. They are at home in the towns as well as in the country, and Monument Valley Park is a favored place for them. A male of this species in the Aiken Collection taken at Ramah, June 5, 1898, is peculiar in having no black on the head, this being rather bright yellow.

Euphagus carolinus. Rusty Blackbird.

Rare; but one record for the County, 3 seen and 2 killed by Aiken at Skinner's, January 15, 1908. There are only a few records of this species for Colorado, and this is the only one south of the Divide.

Euphagus cyanocephalus. Brewer's Blackbird.

Summer resident; common. Arrives the last week in April. Most of them are gone by October first, but it has been known to remain until January 1.

Brewer's Blackbird is one of our most common summer birds, seen everywhere about the ranches on the plains and up into the mountains, where a great many breed, gathering after the breeding season is over into flocks, often of large size. Since Monument Valley Park has been established a number are there every season, at the north end, and L. L. Shaw found

a nest there, May 28, 1912, which contained 3 eggs. At Ramah, June 4, 1898, nests contained young and eggs in advanced stages of incubation. It nests in all sorts of situations, in trees and bushes, on the ground, and even in haystacks.

Quiscalus quiscula aeneus. Bronzed Grackle.

Summer resident; only locally common. Arrives the last of April, the earliest date being April 19, 1899. Departs early in autumn.

The Bronzed Grackle breeds in colonies, and there is one near Buttes on Fountain Creek. The birds probably leave as soon as the young can fly well, and no doubt all leave the County long before winter sets in.

Hesperiphona vespertina montana. Western Evening Grosbeak.

Resident; locally and irregularly common.

The Evening Grosbeak is better known as winter visitor than as a summer bird, for but few of us are favored with a sight of it at the latter season, though Aiken has seen the species in the County every month in the year. And as a winter visitor it is decidedly irregular, for several winters may pass without one being seen, then there will be numbers around town, always going in flocks and feeding in the yards and among the trees. They are usually tame and approachable then, and easily observed. They probably breed in the mountains in this region, but their nesting places have not yet been located.

June 19, 1898, Aiken found in the oak thickets of the lower foothills near Bear Creek a flock of 25 or 30 Evening Grosbeaks, from which he killed five males. Both sexes were together and had probably come down off the mountains to feed on the larvæ of insects that were devouring the leaves of the oaks. The contents of the gizzard of one bird examined

appeared to consist of small black seeds mingled with the insect larvæ. The testicles in all were of the size of large beans and indicated that the birds were either breeding or on the point of doing so.

Pinicola enucleator montana. Rocky Mountain Pine Grosbeak.

Resident in the mountains. More common in winter.

It is difficult for us to say with the information at hand what is the abundance of the Pine Grosbeak in this region, but we do not consider that it is at all common even in the localities where it dwells. It is a mountain bird, and seldom, with us, descends to the lower altitudes, but remains above 9,000 feet most, if not all of the year, and does not seem to be given to those wanderings which bring its eastern consins down from the north into the eastern states, often penetrating a considerable distance south. It was seen and taken by Warren above Seven Lakes, 11,000 feet, in January, and also seen by him on top of Cheyenne Mountain, November 21, 1905. In the case of those seen at Seven Lakes the care-taker at the Strickler Tunnel said they had been about there all winter. They were in the willows when seen. Aiken has had several specimens from near timberline on Pike's Peak.

Carpodacus cassini. Cassin's Purple Finch.

Resident.

Cassin's Finch is a resident of the mountains, where it breeds, coming down to the foothills and edge of the plains in fall and winter, but rather irregularly, not being observed at all some seasons. At this season it is found in flocks, which at first sight seem to be composed largely of females, but many of the supposed females are really males in their first winter plumage, which is practically identical with that of the female. They frequent the trees and bushes along the streams, in the

foothills, and at the bluffs. It is doubtless more or less common in the pines on the Divide, and has been noted at Eastonville early in March. We have no records of its occurrence in the mountains in this region in summer, though it should breed among them as it does elsewhere in the State. Our winter residents are doubtless migrants from more northern localities.

Carpodacus mexicanus frontalis. House Finch.

Resident; common about towns.

House Finches are town rather than country birds with us, apparently preferring the neighborhood of human habitations, and are about the only birds we have which seem able to hold their own against the imported House or English Sparrow. While resident the year through, it seems possible there may be a slight migration, a portion going south in winter, for they do not seem as abundant at that season as in summer, though that is partly accounted for by the fact that the birds do leave the neighborhood of houses and go out among the fields searching for food. However that may be, they return in good season, and in early March the brightly clad males may be heard singing sweetly and courting their mates. They build their nests about houses and other buildings, as well as in trees.

In 1903 a pair built their nest on the cap of a column on the porch at my home, beginning to build April 20. There was one egg in the nest the evening of April 27; 3 eggs on the afternoon of May 1; 4 eggs May 4, but I have no notes of the intervening days. The three days preceding May first the female spent a good deal of time on the nest as the weather was cold. The morning of May 12 there were 3 young in the nest and one egg; about six o'clock in the afternoon I saw the female eat most of an eggshell; possibly the last egg had just hatched. From May 12 to 28 I photographed these young birds daily, sometimes one, sometimes all four. May 26 the largest escaped from me and flew across the street, alighting in a tree, where its mother afterwards fed it; all the remaining young left the nest May 29. (E. R. W.)

Two broods are, sometimes at least, raised in a season, and possibly three. September 3, 1903, young House Finches were noticed which seemed to have just left the nest. Lloyd Shaw found a nest May 26, 1912, containing 4 eggs, and on the 28th there were 3 young; presumably these eggs were laid from the 12th to the 16th of May. June 16, 1912, a young bird just from the nest was seen in Monument Valley Park. Two broods were hatched in one nest in 1913; the first hatched June 2 or 3, the second flew July 25.

The food of the House Finch consists largely of seeds of various sorts. They sometimes eat the seeds of that pest the dandelion, in fact Dr. W. H. Bergtold says the young are largely fed on those seeds. In the fall they have been seen eating the seeds of *Clematis paniculata* which was growing over a porch.

"A comparison of House Finches collected in El Paso County with specimens from California, Arizona and New Mexico, shows the local bird to be consistently darker with broader streaks beneath, olivaceous brown rather than hair brown. White of underparts purer or ashy, lacking the buffy tinge; the red more crimson. Bill and feet more robust and darker. Culmen shorter (10 mm.), little more than depth of bill at base. Average length of 11 males 153 mm.; average of 17 males, Wing, 78.3 mm.; Tail, 61.3 mm.

I conclude that the House Finches of Colorado east of the mountains and probably of southeastern Wyoming are subspecifically distinct from those of California, Arizona and New Mexico at least as far east as the Rio Grande River. If further investigation proves this conclusion correct the more western and southern form becomes *Carpodacus mexicanus obscurus* McCall. Local birds are true *frontalis* since Say's type locality is the Arkansas Valley.

Our House Finches are in part migratory and in part non-migratory. There are the same smoke-soiled birds with us

through the winter which breed here in the summer and there is no evidence that any wintering birds are from more northern localities. In April I meet clean plumaged birds coming north from their winter resort. Flocks of House Finches are seen migrating in autumn; August 13, 1907, I noticed flock after flock passing south along the Fountain at Skinner's six miles south of Colorado Springs. Young birds gather in weedy fields in August where they linger a few days until the autumn moult is completed and then most of them go southward, probably led by old birds. The percentage of these which return in the spring seems to be small.

I first met with House Finches near Cañon City, April 26, 1872; a flock of several hundred were sweeping through the valley. In the May following I found 2 or 3 pairs nesting in the piñon hills northeast of there. I found none nesting in those early days in Cañon City, Pueblo, Colorado Springs, or Denver, but at Trinidad, in July, 1872, I first saw them utilizing human habitations. It was many years before the northern birds took up with the advance of civilization and made their homes in towns. When I returned to Colorado, in December, 1895, after some years absence, I found them frequenting the city. The spring following a pair built their nest in a wistaria vine close under the eaves of my front porch and directly over the steps. They raised a brood and went off with the young as soon as they could fly, and were not seen again until the following spring (1897), when they cleaned and reoccupied the old nest.

When the young in this nest were half grown the parents built a second nest under my neighbor's porch and while the male was attending the first brood the female raised another. In 1898 the breeding impulse was even stronger. The male was first noticed December 27 of the previous year to come and inspect the old nest. At intervals of ten days he came after that for several weeks before he brought his mate. In March the pair cleaned and relined the old nest and the female

began incubating. Soon after the young were hatched a second nest was built adjoining the first and attached to it in which a second complement of eggs was laid and the female sat on these while the young were growing in the first nest beside her. When the second brood were hatched a third clutch of eggs was laid in the nest now vacated by the first brood and a third brood successfully reared. A chronology of the domestic affairs of the pair for the next year, 1899, follows:

March 8. Male bird seen inspecting the old nest.

April 13. Both birds had been house-cleaning since March 17 and had relined the original nest.

April 25. Female sitting and the male keeps out of sight.

May 8. Five young hatched.

May 28. Nest deserted and both parent birds presumed to be with the young instructing them to provide for themselves, but returned a few days later.

June 11. Female incubating second laying.

June 23. Second brood of young several days old. Male not seen but heard singing in early morning.

July 3. Young of second brood left the nest.

In 1900 the male was seen inspecting the nest January 13, and the female joined him February 23. March 8 the old nest was relined. The first laying of eggs was thrown out of the nest April 16 but April 20 the female was incubating a fresh set, and May 11 the young were about a week old.

In 1901 one brood was reared.

In 1902 the pair seemed much annoyed to discover that English Sparrows had occupied their nest as a roosting place but finally renovated it and occupied it about May 20. One brood raised.

In 1903 the pair came early and finding their nest demolished by sparrows built elsewhere in the neighborhood.

In 1904 the pair appeared March 3 and after lingering about the old nest sometime began carrying material from it across the street where the nest was constructed. Work done by the female closely attended by the male. English Sparrows then built their own nest on the platform of the denuded finch nest.

In 1905 the pair of House Finches came February 26 and for nearly a month kept near the old nest which they seemed bent on reoccupying, but on March 11 a catastrophe occurred which closed their life history. In attempting to destroy the pestiferous English Sparrows I accidentally killed both finches. much to my regret. They had for ten years been members of my domestic family. Their skins are preserved in the Aiken Collection in Colorado College, their original numbers being, male, 4577, and female, 4578.

My excuse for relating this extended history is that I believe that some light may be thrown upon the breeding habits of various other species of birds by the application of my narration. I have space to point out but one point here. I assume and am convinced that the birds were in their first reproductive year when they built the first nest. They reached the height of reproductivity in the third year when they raised three broods. In succeeding years they dropped to two broods and then to one. This may be accepted as a law or rule applicable to other species whose habit is recorded of producing two or more broods in a season. We may conclude that the more vigorous pairs produce two or more broods some seasons but other pairs may produce but one.

Breeding male House Finches show a variable amount of red in the plumage. Those with the least I have supposed to be birds of the previous year which would acquire the full plumage at succeeding moults, concluding also that deficiency of red characterized all birds of the year. I think this is the prevailing view. In 1907 I made investigations which throw some light on the subject. Young birds take on the coat worn

through winter and the following summer about three months after leaving the nest. A large proportion of them and of adults as well moult in August. The new feathers grow out through the feathers of the old coat, gradually displacing them.

I observed at this time that moulting young males were acquiring as extensive a distribution of red as the brightest colored adults, in fact after completion of the moult in both young and adult they are not distinguishable. Several specimens illustrating this moult were preserved. Evidently then the majority of young acquire the perfect coat at the first autumnal moult.*

Later in 1907, on October 4, I obtained an undoubted young male just completing its moult which is indistinguishable externally from a female at the same season except perhaps for a faint tinge of red on the jugulum. It suggests a parallel case to that of *Carpodacus cassini* in which young males regularly take the coat of the female at the autumnal moult. What may take place in further development of the plumage in such cases as that of this imperfectly marked House Finch is open to further investigation. Possible conclusions are that it might develop some increase of red at the breeding season and acquire a perfect coat at the second autumnal moult, or it might develop at the second moulting a phase of scanty red diffusion that would exist through life and prove an individual variation, perhaps an individual characteristic transmittable to progeny.

Orange-red mingled with or displacing crimson-red in House Finches is accepted as indicating age. A male taken May 22, 1904, shows a scanty reddish area of the orange shade, so probably this bird lived a number of years without increasing the amount of red.

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*The red of the autumnal coat remains pinkish through early winter, gradually deepens toward spring, and acquires its greatest intensity at time of breeding without a spring moult or apparent abrasion.

Finally, it seems probable that these birds acquire no material increase of the red area after the second summer, and that the extent of red is not dependent on age."

(C. E. A.)

Loxia curvirostra minor. Crossbill.

Resident in the mountains; locally common.

Aiken found several about St. Peter's Dome in June and July, 1907; also at Palmer Lake, June 26, 1907. Allen and Brewster reported seeing a flock of about thirty at Austin's Bluffs, April 26, 1882, and also noticed a few both there and elsewhere at both earlier and later dates. Two birds taken at St. Peter's Dome on June 13 were apparently just completing their moult, and one taken at Palmer Lake, June 26 was in the midst of moulting.

Loxia curvirostra stricklandi. Mexican Crossbill.

There is in the Aiken Collection a male Crossbill collected on Turkey Creek, May 22, 1874, which is much larger than the other birds just mentioned, and has a much larger bill. Sclater referred this to *stricklandi*, while Oberholser calls it *bendirei* Ridgway, but this latter subspecies has not as yet been recognized by the A. O. U. There is a female in the same collection belonging to the same form, and having a label with the same date, but which was really taken in the White Mountains, Arizona, in 1876, by Aiken.

Leucosticte tephrocotis tephrocotis. Gray-crowned Rosy Finch.

Winter resident; irregularly common.

This species, in common with the two succeeding species of Rosy Finch, is a winter visitor with us, but quite uncertain in its occurrence. Probably they are fairly regular in their appearance in the mountains, but lower down, below the foothills, they do not come so often, though Aiken has collected a

number in various winters near Colorado Springs and Colorado City. Occasionally it comes right into town; thus one was seen December 29, 1902, near the Plaza Hotel in Colorado Springs, and February 12, 1903, two were seen feeding with a large flock of Horned Larks on millet seed which had been put out for the latter. They are often about the caretaker's house at Lake Moraine in winter. Rosy Finches are sociable birds and are almost always found in flocks, frequently of many individuals, and sometimes including all four of the forms which are found in Colorado. In April, 1874, a flock fed about Aiken's dooryard in Colorado Springs and he captured some alive and kept them in a wire cage for a time. They evinced no fear and would occasionally sing an unpretentious trill.

Leucosticte tephrocotis littoralis. Hepburn's Rosy Finch.

Winter visitor; not common.

This species is found associated with the others, but is not nearly as common. Aiken has taken a few near Colorado Springs and Colorado City, and Warren took two at Lake Moraine, December 12-13, 1906, and saw one a mile southwest of Colorado City, November 7, 1913, in company with about a dozen of the preceding species.

Leucosticte atrata. Black Rosy Finch.

Winter visitor; not common.

The type of this species was shot by Aiken at Cañon City and the name *atrata* was suggested by him to Ridgway. The Black Rosy Finch has been met with a number of times in El Paso County where it occurs as a winter visitor with considerable regularity and at all altitudes. Like others of its kin it is a mountain bird but is sometimes driven down to the plains by snow. Aiken obtained specimens from the summit of Pike's Peak in 1877, Colorado City in 1878, and from near Colorado Springs in 1883, while Warren found it at Lake

Moraine in December, 1905, and March and December, 1906, and secured a good series of specimens.

Leucosticte australis. Brown-capped Rosy Finch.

Resident; common.

The Brown-capped Rosy Finch is a resident species, living in summer on the summits of the mountains above timberline, and was first met with by Aiken on the summit of Pike's Peak, July 4, 1873. The nest has never been found, but if its nesting habits are like those of the Gray-crowned species, or rather the Sierra Nevada Rosy Finch, the nest will be found hidden under stones in rock slides, for such was the situation of the nest of its relative recently discovered in California. In summer it may be seen flitting around the mountain slopes, searching for food, often, even in what would seem to be the breeding season, two or three together. In autumn, when the weather becomes more severe, and food possibly more difficult to secure, they go lower down and join with their visiting relatives, the three preceding species, and make up large flocks, and in these it often seems to be in a minority as compared with the Gray-crowned. No doubt some of this species migrate farther south in winter, leaving their places to be filled by the others.

Acanthis linaria linaria. Redpoll.

The Redpoll is a decidedly rare winter visitor with us, and not often seen; possibly it may be more common in the mountains; Warren found it at Lake Moraine in December, 1906. There are specimens in the Aiken Collection taken in the winter of 1878-9, near Colorado Springs, and also one collected in Fremont County, April 25, 1872, which seems an unusually late date. Dr. W. W. Arnold reported a flock of 25 about Colorado Springs the winter of 1910-11, and noted that the birds ate the cottony scale on the maple trees.

Astragalinus tristis tristis. Goldfinch. "Wild Canary."

Summer resident; common.

It is somewhat difficult to separate the records and occurrence of this from the following subspecies, as a sufficient series of specimens for the purpose is lacking. With the exception of the few which sometimes spend the winter the Goldfinches arrive early in May for the summer and are quite common over the County below 7,000 feet.

Astragalinus tristis pallidus. Pale Goldfinch.

Summer resident; common. Found occasionally in winter.

Aiken considers that the Goldfinches which spend the winter in the County are all *pallidus,* and that the summer residents along the foothills are mainly this species, while most of the typical form are found toward the eastern portion of the County. More collecting of specimens is, however, necessary to fully settle these points. Summer birds soon lose the paler edges of the feathers by abrasion and are then not noticeably different from the preceding form.

Astragalinus psaltria psaltria. Arkansas Goldfinch.

Astragalinus psaltria arizonæ. Arizona Goldfinch.

Astragalinus psaltria mexicanus. Mexican Goldfinch.

Summer resident; common. Typical *psaltria* usually arrives the third week in June; extremely early dates are April 21, 1900, and May 13, 1898, and specimens taken at these dates were still in their winter dress. Most of them leave in September and October; an unusually late date is that of a specimen from Beaver Creek, Fremont County, November 11, 1872. This is still in summer dress.

The A. O. U. Committee has eliminated the last two of

the above named forms from its Check-List, regarding the differences in color as being due to age, this being the position taken by Oberholser in a paper published in 1903, in which he states that a series of summer males from Colorado Springs "exhibits all gradations from the green-backed to the black-backed forms, representing thus *psaltria, arizonæ,* and *mexicanus*—all breeding at the same place!" It is very true that the series of males in the Aiken Collection represents these gradations, but there is one point that has been overlooked with regard to the occurrence of these birds in El Paso County, at least, and that is *psaltria* alone is the breeding form, so far as at present known, the dark forms not making their appearance until later, *arizonæ* coming in July, and *mexicanus* the very last of July and first of August, and their actions then would indicate that they have but just arrived, nor have any dark colored birds been discovered breeding in the County.

The dates of skins of *psaltria* are April 20, 1900; June 25, 1898; July 23, 1899; August 15, 1907; September 2 and 5, 1897. Of *arizonæ,* July 16, 1872 (Fremont Co.); August 5, 1898 (2); August 6 and 7, 1897; August 12, 1907. A bird *seen* by Warren, June 15, 1912, appeared to be this form. *Mexicanus,* August 4, 1898; Salida, Chaffee Co., August 3, 1908; 5 or 6 *seen* by Aiken in yard August 11, 1907. Dr. Bergtold reported seeing one in Denver, June 30, 1908, but did not collect it.

The evidence of the specimens and of field observations agree very well, though it is only fair to state that it is difficult to always distinguish *arizonæ* from *mexicanus* in the field, as the birds almost invariably appear darker than they really are. These Goldfinches are often seen about the town on vacant lots, especially where sunflowers have grown up and gone to seed, and are easy to approach and observe, so that one can readily study them. An examination of the plumage of these specimens gives us no clue, for it seems perfectly fresh and unworn. A possible explanation which occurred was that

Fig. 35. *E. R. W., Photo.*
THE NEST UNDER THE PROTECTING BRANCH.

Fig. 36. *E. R. W., Photo.*
NEST AND EGGS OF GRAY-HEADED JUNCO; A CLOSE VIEW.
Near Golden, Colo.

Fig. 37. *E. R. W., Photo.*
MALE BLACK-HEADED GROSBEAK.
Ivywild.

Fig. 38. *E. R. W., Photo.*
COLONY OF CLIFF SWALLOWS.
Weld County, Colo.

the differences in color might be due to the wearing away of the outer portions of the feathers leaving a dark inner portion exposed, but the plumage of *psaltria* shows no dark portions of the back feathers which could be thus exposed by wear, though we have examined specimens taken August 15 which are much worn, and as stated above the dark skins show no indication of any such wear.

To summarize: *Psaltria* is the first of the three forms to appear here in spring, and seems to be the breeding form; *arizonæ* makes its appearance in July; while *mexicanus,* the darkest of the three, does not appear until about August first. After that time all three forms are to be found and in flocks together.

We have tried to present the facts in this puzzling case as clearly as possible, feeling the settlement of the matter by the A. O. U. Committee is not as satisfactory as it might be.

Two of the males in the flock noted as seen in yard August 11 were quarreling over a female.

Besides sunflower seeds the species eats almost any sort of weed seeds, including those of the dandelion.

Spinus pinus. Pine Siskin. Pine Linnet. Pine Finch.

Resident; common.

Pine Siskins are probably found at some season of the year over all the County where there is any cover for them, but they are rather irregular in their occurrence, at least in winter, and some seasons but few will be noted. The winter of 1910-11 a large flock was about the north end of Monument Valley Park, while the following winter but few were seen. It ranges at least as high as Lake Moraine, where Aiken has taken it. May 16, 1913, a pair had a nest at Ivywild, in a cottonwood tree, well out on a branch 30 feet above the ground. The birds could be plainly seen at the

nest and identified. Dr. Arnold has seen this species eating the cottony scale on maples trees.

Passer domesticus. House Sparrow. English Sparrow.

Resident; common about towns.

The House Sparrow was first seen by Aiken in Colorado Springs in 1895, on his return after an absence of a few years. At that time there were several flocks about the town, most of which had probably been hatched that season, and numbering about 50 birds; the following year it was estimated there were 500 birds in the same area. The species probably reached the town in the spring of 1895.

While the English Sparrow, everything considered, is a pest and a nuisance, it does do a little good, possibly due to the fact that it is greedy and omnivorous, and will eat almost everything which comes its way. It has been seen to catch grasshoppers and feed the fledged young with them in the street; to work about in the grass of a lawn, and dig up worms or grubs of some sort, probably cutworms; also to eat some sort of plant lice on the branches of trees.

A good many summer in Monument Valley Park, and then leave in the fall, presumably going up among the houses for the winter, though it is probably there is a partial migration in autumn as there are not as many of the birds around the town in winter as in summer, and they become numerous again in the spring.

September 24, 1912, a partially albino male House Sparrow was seen near a residence in Colorado Springs. There were one or two white feathers in the right wing, either the last primaries or first secondaries, and one or two of the inside feathers on the right side of the tail were white. When the bird flew these white feathers in the spread wing and partly spread tail made a striking contrast with the rest of the plumage. It was never seen again though often looked for.

In spring, before they begin to breed, on a bright day, especially after a storm, a flock will often gather on a bush or the roof of a building, and sing and twitter together, having as much of a song as some of our other sparrows.

Aiken has traced the progress across the plains of this undesirable alien by ascertaining from residents through western Kansas dates of its appearance at different points along the line of the Rock Island Railroad. He estimated that the westward advance of the invading army of sparrows was at the rate of about 50 miles a year.

Plectrophenax nivalis. Snow Bunting.

Winter visitor; rare, but one record of its occurrence in El Paso County, a pair taken by Aiken at Colorado Springs, in 1874. These are mounted and in the Colorado College Museum.

Calcarius lapponicus alascensis. Alaska Longspur.

Winter visitor; very irregular.

In the Aiken Collection are specimens taken near Colorado Springs, January 5, 1874, at which date a large flock was reported to be near town, and 20 specimens were brought in; specimens were also taken December 28 and 29, 1876; January 12, 1877. In January, 1884, Warren took one on each of three different days, always with a large flock of Horned Larks.

Calcarius ornatus. Chestnut-collared Longspur.

Winter visitor; common in certain localities. Arrives in September, Aiken having seen it September 12, 1897, on the plains east of Colorado Springs; later in the same year, October 3 and 13, he found it at Broadmoor Ranch, his notes mentioning the Longspurs being in alfalfa fields which had been mowed close. The species was near Colorado Springs in February, 1899. In the seventies, when living on a ranch

on Turkey Creek, Aiken used to frequently see this and the following species on the open ground between there and Fountain, out of the foothills. Allen and Brewster saw about 20 May 9, 1882, securing five. This is the latest spring date we have.

Rhyncophanes mccowni. McCown's Longspur.

Winter visitor; irregular. Not quite as common as the Chestnut-collared.

January 14, 1884, Warren took one just north of Colorado Springs. This and the Alaska Longspurs were taken at a time when we had severe cold weather with a little snow on the ground. On the north edge of the city, somewhere about the end of Wahsatch Avenue, were large flocks of Horned Larks, and it was with these the Longspurs were found. Allen and Brewster took one May 9, 1882, with the before mentioned flock of Chestnut-collared Longspurs.

Poecetes gramineus confinis. Western Vesper Sparrow.

Summer resident; common. Arrives usually about April 18, the earliest date being April 9, 1899. Are probably gone by about October first, the latest dates we have being September 25, 1913, and October 1, 1872.

The Vesper Sparrow is an abundant bird in the open parts of the County, and should be found in the open spaces in the mountains up to at least 9,000 feet. Nests in May, an unusually early date being a nest found by Warren near Colorado Springs, May 5, 1904, which contained 3 eggs. The nest is always on the ground, often in a depression, and usually hidden under a tuft of grass, a bunch of weeds, or a low bush.

Passerculus sandwichensis alaudinus. Western Savannah Sparrow.

Summer resident above 7,000 feet; common. Most of

them arrive the last of April and early in May, an extremely early date being March 19, 1899. They begin to move south the last of July, and are all gone by the middle of October.

In spring the Savannah Sparrow is found around meadows and marshy places, taking refuge in old dead weeds when disturbed, and is quite apt to be about alfalfa fields during May and to June first. In the autumn it is around weedy fields and grassy places. Before June first most of them go into the mountains and northward, breeding in this County from 7,000 to 9,000 feet. It has not been found breeding along the Fountain. A pair seen near Ramah in June appeared to be getting ready to nest. The nest is placed on the ground, well hidden in the grass.

Ammodramus bairdi. Baird's Sparrow.

Migrant, but rare in spring, there being but one record for that season, May 6, 1873. Autumn records are more frequent, Aiken, in 1897, securing specimens at various dates from August 22 to October 13; in 1898 it appeared as early as August 10. Most of these specimens were taken about weedy fields near the Broadmoor Ranch south of Colorado Springs.

October 5, 1872, Aiken killed one on the prairie 11 miles east of Fountain which was practically a rediscovery of the species which had been unknown since Audubon first described it in 1844 from a specimen taken in eastern Montana, near old Fort Union, North Dakota. This specimen of Aiken's was described by him as a new species, *Centronyx ochrocephalus,* as it did not agree with the descriptions of any other sparrows known at that time, and as a matter of fact was in a different plumage from the bird described by Audubon. Mr. Robert Ridgway examined Aiken's bird and expressed the opinion that it was a new species.

It is found on the prairies and in fields, but never in brush or bushes, at least as observed in this region.

Ammodramus savannarum bimaculatus. Western Grasshopper Sparrow.

A rare autumn migrant, not observed in spring. The only records for the County are specimens taken by Aiken at Ramah, July 15, 1898, and near Colorado Springs, July 20, 1898, and August 8 and September 24, 1897.

Chondestes grammacus strigatus. Western Lark Sparrow.

Summer resident; common. Arrives about first week in May, April, 17, 1907, being the earliest date. Departs in September, the latest date being September 25, 1913.

Common on the plains, and probably in the open parts of the Ute Pass region. It may raise two broods as young not long from the nest have been seen on different occasions in the first two weeks in August, which would be late for a single brood unless the first nest had been destroyed.

Zonotrichia querula. Harris's Sparrow.

Rare, but two records for the County, a female taken by Aiken at Buttes, January 24, 1908, which was in company with Juncos and Tree Sparrows; and one seen by Lloyd Shaw and others in Monument Valley Park, February 14, 1914.

Zonotrichia leucophrys leucophrys. White-crowned Sparrow.

Summer resident in the mountains; common. Arrives about May 4. Allen and Brewster saw it April 24, 1882. It has been seen as late as October first at 9,500 feet, and October 12 in Monument Valley Park.

Just about the time the Gambel's Sparrows are beginning to leave in the spring the White-crowns make their appearance, and are found along the lower streams for a month before they retire to the mountains for the breeding season. They were noted by Warren in Monument Valley Park as late as

June 2, 1913, and Aiken saw 6, collecting one, at Ramah, June 4, 1898.

This species breeds exclusively in the mountains, probably few breeding below 9,000 feet, and from that elevation to above timberline. The nest is placed in low bushes of various kinds, often evergreens, and never very far above ground. Drew stated that in the San Juan Mountains it raised two broods, the first at the lower part of its range, and then a vertical migration was made to above timberline where the second brood was raised.

On a trip to Strickler Tunnel July 9-10, 1899, Aiken found White-crowned Sparrows "abundant in willows above timberline, and in the cañon below Seven Lakes, where birds were seen skulking among the low bushes, where they evidently had nests though they could not be found. The males mount to a top twig and watch the intruder quietly from a distance or utter a chirp of alarm on close approach. The song from near by may be represented by the syllables *oo-dree-e-e, twee-ty too.* Inhale the "oo" through the teeth and exhale the "dree" in higher key. Some times a low inhaling sound follows the effort. Birds above timberline were in full song. Those lower down where nesting was probably further advanced were more quiet and skulking."

Zonotrichia leucophrys gambeli. Gambel's Sparrow.

Migrant; common in spring and autumn; a few winter. Arrives usually about the middle of March, February 27, 1899, being the earliest date, and remains until the first week in May. May 11, 1898 is the latest spring date we have. The fall migration begins about the first of October, September 28, 1907, being the earliest date, and tthe majority have gone on by the early part of November.

While with us these birds frequent the brush along the streams and in the ravines, feeding on weed seeds and anything else they may find to their taste. Just before they leave in the

spring they are often found in company with their relatives, the White-crowns, who have just arrived for the summer.

Spizella monticola ochracea. Western Tree Sparrow.

Winter resident; common. Arrives about the first of October, the earliest date being September 22, 1912. They begin to leave the last of February and early in April are nearly all gone. The latest spring date is one taken by Aiken, April 20, 1900.

The Tree Sparrow is one of our commonest winter birds, found everywhere about the bushy places of the foothills and plains, but does not go far into the mountains in winter. While it is often associated with various juncos, yet they seem disposed to keep somewhat apart, and when a mixed flock is disturbed the sparrows will often separate to a considerable extent from the others. In Monument Valley Park, the winters of 1911-12, many have patronized the food tables where millet and other seed is put out for them. Though they come to these tables in large numbers they are rather shy while there and will not permit a close approach. They are not entirely dependent on these tables, however, even in the park, and can be seen hunting food for themselves in the weeds and grass there, possibly for variety's sake. As their food is practically all seeds in winter, the Tree Sparrows and Juncos destroy great quantities of weed seeds during that season.

Spizella passerina arizonæ. Western Chipping Sparrow.

Summer resident; common. Arrives April 10 to 20, the earliest dates being March 23, 1900 and March 24, 1899. Leaves in October, probably are about all gone by the 15th; the latest fall date is October 24, 1897.

The Chipping Sparrow is one of our most abundant summer residents and breeders; nests in trees and bushes along streams and in gulches, Aiken noted a full fledged brood in Colorado Springs June 21, 1897; very likely two broods

are raised in a season. The last of August and first of September they gather in large flocks, composed of adults and young of the year, the latter often hard to identify in the field, and are found about the brushy and weedy places everywhere. When the young are fledged and able to take care of themselves the males separate into little flocks by themselves and the females and young are in other flocks. The males migrate first, which is a common habit with various birds.

Spizella pallida. Clay-colored Sparrow.

Migrant; rather common on the plains. Arrives about the 7th of May and found until about the 25th. It has been taken in the fall migration as early as July 25th, and by the middle of September all have gone on.

Often found in flocks along the more open stream bottoms, and in weedy fields, avoiding the thickest brush; also found on the prairies.

Spizella breweri. Brewer's Sparrow.

Migrant; common; a few breed on the plains. Arrives about the first week in May, earliest date April 30, 1873 and 1898. The fall migration has passed by the middle of September.

Brewer's Sparrow probably breeds in small numbers in the County. Aiken found it July 14, 1897, at Ramah; June 25, 1899, at the Garden Ranch, where several pairs were breeding; and took a nestling near Colorado Springs, August 6, 1898, and also young in downy plumage August 22, 1897. Breeds in low bushes, apparently preferring sage brush and greasewood, of which there is but little in the County; here it is found about tthe scrubby bushes along outcropping rock ledges. Aiken recorded the song as *bz-z-z te-e-e-e-e-e.*

Junco aikeni. White-winged Junco. Aiken's Junco.

Winter resident; common. Arrives the middle or latter

part of October, the earliest date near Colorado Spring being October 20, 1911, and the last spring date being April 11, 1882, by Allen and Brewster, probably most of them are gone by April first.

Possibly this and the other Juncos go to the higher elevations on their first arrival in fall, for Lloyd Shaw reported seeing them in Jones Park, 9,000 feet, October 1, 1911.

This species varies considerably in abundance during different years, and some seasons it is not at all plenty; the winter of 1912-13 seemed to be an example of this. On the other hand the winter of 1909-10 it was unusually numerous: near Austin's Bluffs there seemed to be three times as many of this as of *J. mearnsi* as shown by speciments shot indiscriminately and field notes made at the time. The species seems to prefer the foothills and bulffs, and to keep away from the valley streams. It was found at Lake Moraine March 8 and 9, 1906. The first specimens of this species known to science were discovered by Aiken in Barnes's Cañon in December, 1871.

Junco hyemalis hyemalis. Slate-colored Junco.

Winter visitor, not common. Probably arrives and departs at the same time as the other Juncos. The latest spring date is April 25, 1899.

The rarest of our Juncos in winter but during a short period of autumn and spring migration quite common, sometimes in large flocks.

Junco hyemalis connectens. Intermediate Junco.

Winter resident; not common. Times of arrival and departure no doubt the same as the other Juncos.

About as common as *hyemalis, shufeldti,* and *montanus,* much more common in migration than in winter.

Junco oreganus shufeldti. Shufeldt's Junco.

Winter resident; not common. Arrives and departs at the same time as the other Juncos, extremes being October 15 and April 10.

For the names of this and the two following species we follow Ridgway rather than the A. O. U. Check-List as it seems to us that the treatment of the Juncos in the latter is exceedingly unsatisfactory.

Shufeldt's Junco is not uncommon during the winter but is not found in any such numbers as the Pink-sided or Gray-headed Juncos, or even the White-winged in its abundant seasons. In the field, without the use of a glass, it is often difficult to distinguish between this and the Intermediate and Montana Juncos, except when one is very close. At a near view, the very black head and pink sides of the Shufeldt's make it easily identified, but the females are difficult if not impossible. As a writer in Bird Lore says:

"For the female of the species is more puzzlin' than the male."

Warren took one at Lake Moraine in December, 1906, and a black-headed Junco of some sort was seen there in March, 1906.

In migration this species is quite common.

Junco montanus. Montana Junco.

Winter resident; not common. Arrives and departs at much the same times as the other Juncos.

There are seven specimens in the Aiken Collection taken at various date from October 25 to April 24. This is probably the least common of our Juncos in Winter; in the migrations it is more abundant. The males arrive from the south about February 25 and are around for ten days or more, and the females follow somewhat later in March.

Junco mearnsi. Pink-sided Junco.

Winter resident; common. Arrives early in October, possibly usually not until the second week; earliest record September 30, 1913. Departs in April, lingering longer than either of the Juncos previously mentioned. Latest date May 4, 1872.

The most numerous of the Juncos, and usually forming the greater proportion of the flocks one meets with, but in the winter does not usually go high into the mountains, keeping more to the foothills and plains. It is always to be found in Monument Valley Park in winter with the flocks of Tree Sparrows. Possibly the reason they stay later in spring than the other species is that they have not so far to go to reach their breeding grounds, as many spend the summer in Wyoming.

Junco phæonotus caniceps. Gray-headed Junco.

Resident; common.

This, our resident Junco, breeds commonly in the mountains down to 7,500 feet. It spends the winter in the foothills and on the plains in varying numbers, but it is safe to say that at that season it is always outnumbered by the Pink-sided Junco, and frequently by the White-winged. It prefers the foothills to the plains. Sometimes flocks of Juncos are seen which contain a large percentage of this form; one good-sized flock seen by Warren on Bear Creek near the mouth of the cañon, November 18 and 20, 1912, seemed to be fully one half of this species, the rest Pink-sided; usually the proportion is much smaller. Ordinarily but one or two at a time are seen in Monument Valley Park. The majority of our summer birds probably go south in winter, many of the winter residents coming from other localities.

The nest is built on the ground, sometimes in a cavity in a roadside bank or a stream bank. One found by Rockwell

and Warren in Jefferson County was sunken in the ground so that the rim was flush with the surface. The nest proper was made of grass, coarse outside, lined with finer, with a few horsehairs intermingled. This was under a Douglas's fir tree, and nearly covered by a spreading branch which grew out almost at the foot of the tree and actually rested on the ground over the nest. This nest contained four fresh eggs and is now in the Colorado College Museum. Taken May 30, 1912.

July 10, 1899, Aiken found a nest with five young a week old at the Strickler Tunnel, 11,500 feet. The first nest of the species known to science was found by Aiken, and the description was published in 1875.

Aiken took two of the birds at Ramah, May 16, 1904, a rather late spring record for the plains. One was also taken May 16, 1908, at Buttes.

Melospiza melodia montana. Mountain Song Sparrow.

Summer resident; not common. A good many spend the winter, and it is abundant in migration. The spring migration seems to begin about March first, and in fall most of the birds have gone on by the last of October.

As a winter resident the Song Sparrow is no doubt irregular. November 8, 1897, Aiken took two on Fountain Creek; the 22nd he took three and saw about a dozen; they were not found December 6th following at the same place. At Skinner's, January 15, 1908, he took 3 and saw 20. At Buttes, January 24, 1908, many were seen. There is a skin in the Aiken Collection taken February 6, 1873.

Warren took one on each of the following dates: December 4, 1882, December 12 and 14, 1883. One was seen February 23 and 24, 1913, in Monument Valley Park and also later on in March. November 17, 1912, two or three were seen in the Park, and seemed to hold themselves aloof from the numerous Tree Sparrows. December 22, 1912, one was also seen there.

December 8, 24, and 28, 1913, after the unusually heavy snowstorm of that year, one or two were seen in the Park.

Certain specimens from this region have been identified as *M. m. melodia,* but are not typical.

Melospiza melodia juddi. Dakota Song Sparrow.

A Song Sparrow taken by Aiken near Colorado Springs, March 20, 1898, has recently been identified by H. C. Oberholser of the Biological Survey as *Melospiza melodia juddi.* This is the first record of this subspecies for Colorado.

Melospiza lincolni lincolni. Lincoln's Sparrow.

Summer resident in the mountains; common. Arrives in April, there being a considerable variation in the first arrival dates, from April 9, 1899 to April 30, 1898. Near Colorado Springs the migration lasts until the middle of May, and June 4-7, 1898, Aiken found it at Ramah, still migrating. A pair was noted south of Colorado Springs the first week in June, 1897.

Lincoln's Sparrow breeds in the mountains, from 8,500 feet possibly to timberline, though we have no exact information as to the upper limit of its breeding range. It prefers the willow thickets in the mountain parks.

Melospiza georgiana. Swamp Sparrow.

Rare, but one occurrence known in the County, a bird seen near Broadmoor Ranch by Aiken, August 8, 1897.

Pipilo maculatus arcticus. Arctic Towhee.

Winter resident; not uncommon. Earliest autumn date, November 11, 1909; latest spring date, May 12, 1878.

Most of out winter towhees are probably the Arctic Towhee. They are found usually about the oak thickets at the lower edge of the foothills and in the bluffs, industriously

scratching among the leaves for whatever they can find in the way of food.

Pipilo maculatus montanus. Mountain Towhee.

Summer resident; common. Winter resident; rare. The spring migration seems to begin early in April and is in full swing by May 1. Most of the birds are gone by the last of October.

A few individuals of this species spend the winter with us, just how many it would be difficult to say without collecting every Towhee one sees. The following are winter dates of specimens from the County identified by Oberholser: January 16, 1910; March 12, 1877; December 13, 1909. There is also one taken March 28, 1878, which might be either a winter resident or an early spring arrival.

A common breeder up to above 7,000 feet frequenting very largely the oak thickets in the foothills, bluffs, and mesa gulches. Aiken found a nest with four eggs May 29, 1872. A pair probably bred in the Monument Valley Park in 1913.

Pipilo fuscus mesoleucus. Cañon Towhee.

Rare; there are a few pairs locally distributed along the lower edge of the foothills. A specimen in the Aiken Collection was taken at Red Rock Cañon, April 13, 1878. The winter of 1907-8 one or two were constantly seen on Camp Creek, not far from Colorado City. Usually but one was seen, but Aiken saw two January 29.

Oreospiza chlorura. Green-tailed Towhee.

Summer resident; common. Arrives about May 1; earliest date April 27, and by May 7th the species is here in full force. It appears to be all gone by October 1.

This species is most numerous in migration, probably comparatively few breed below 7,000 feet. A pair no doubt

bred in Monument Valley Park in 1913 as they were seen constantly about a certain dense thicket during May and into early June, and July 27 one was seen at the same place. At least two males were seen courting their mates in the park in May and their actions are interesting and differ from their ordinary habits. Instead of skulking in the brush and dodging out of sight when an intruder appears, the bird perches in a tree, spreads its tail out into a fan, and erects the feathers on the head until the red cap makes quite a respectable little crest, and sings its love song. While the bird is thus engaged one can approach quite closely. "Its call note is *pé-a-wée,* rather weak, and with something of the cat-like mewing tone of the Catbird. Its song is one of the finest of the finches, resembling the thrushes in variety, modulation and sweetness, but lacking in volume." C. E. A., ms. notes.

This Towhee wanders to considerable elevations, breeds to 9,000 feet, perhaps more. Aiken noted it at the Strickler Tunnel and Seven Lakes, July 9-10, 1899; Warren saw it at Lake Moraine August 30, 1905.

Zamelodia melanocephala. Black-headed Grosbeak.

Summer resident; common. Arrives about May 10. Are all gone by September 1. Found commonly in thickets along streams in the foothills and along the valleys; probably does not go much above 7,000 feet. Breeds early in June, though nesting may continue through the month. Aiken found a nest with three eggs near Colorado Springs, June 19, 1898, and three nests near completion the same day. Young of the year are common by August first. A female was sitting on eggs near Ivywild, June 3, 1913.

A Black-headed Brosbeak kept in a cage for 8 years by a Mr. Feets of Colorado Springs took on a peculiar plumage in the last year. Aiken went to see it July 21, 1899 and notes as follows:

"The upper parts are wholly black. Beneath it is of the

Plate XXI.

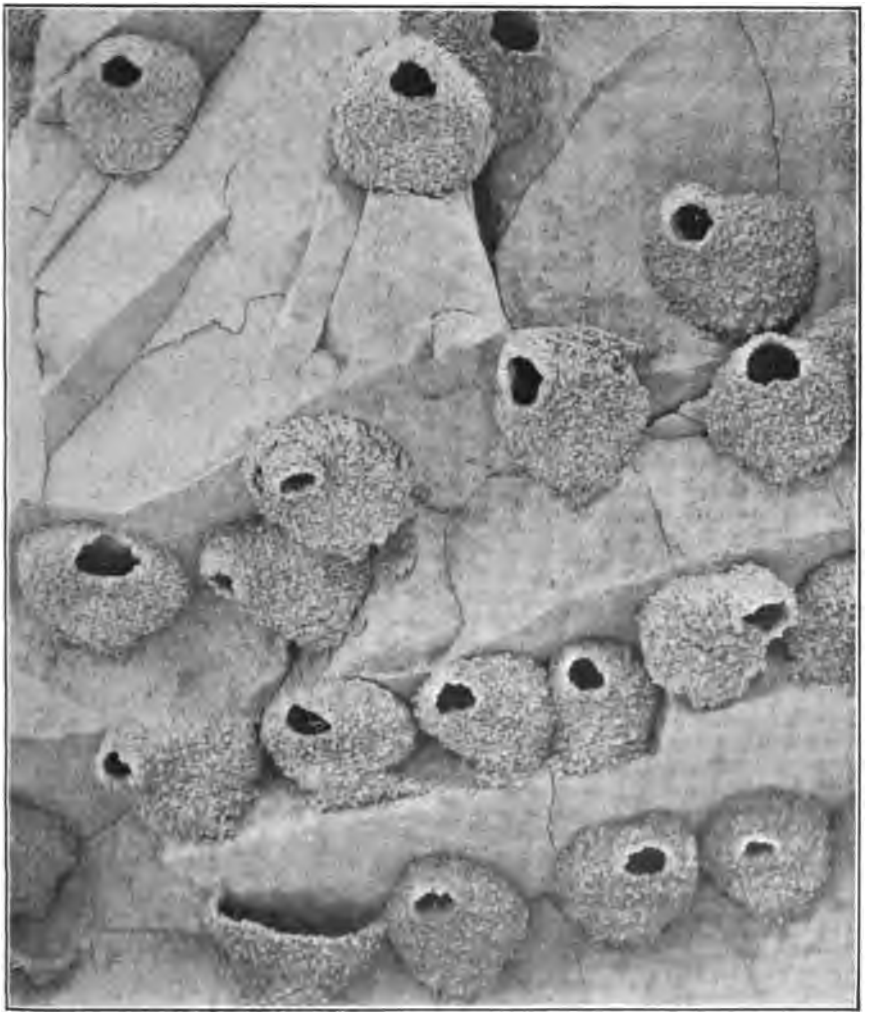

Fig. 39. *E. R. W., Photo.*
CLIFF SWALLOWS' NESTS.
A part of the colony shown in Fig. 38.

Fig. 40. *E. R. W., Photo.*
WHITE-RUMPED SHRIKE.
Garfield County, Colo.

Fig. 41. *E. R. W., Photo.*
WHITE-RUMPED SHRIKE'S NEST.
Elbert County, Colo.

normal autumnal shade of brownish red, but this color is obscured or hidden by sooty black tips to the feathers. The general effect is that of a black bird." The bird died late that autumn.

Guiraca cærulea lazula. Western Blue Grosbeak.

Summer resident; not common. Arrives about June 1.

There are comparatively few records of the Blue Grosbeak for El Paso County; it has been taken or observed at Colorado Springs, Skinner's, Fountain and Buttes at intervals from 1872 up to the present time, and the dates run from June 1 to August 13, nearly all being June occurrences.

Passerina cyanea. Indigo Bunting.

Rare; but one record for the County, a male taken by Aiken May 8, 1872, at his ranch on Turkey Creek.

Passerina amœna. Lazuli Bunting.

Summer resident; common. Arrives about the first week in May; departs in August and September.

This beautiful bird is quite common in the brush along the streams; a number seem to spend the summer in Monument Valley Park, where one day three of the brightly clad males were seen on a food table. Aiken found, June 19, 1898, in rose bushes on a hillside near Bear Creek a nest of this species containing 3 eggs and one Cowbird's egg. He notes the song of one bird heard as *tsup, tsup, tsip,-tsip,-tsip,* uttered in loud clear tone and repeated at intervals of a minute or so. The vertical range of this bird extends but little if any above 7,000 feet.

Spiza americana. Dickcissel.

There is a single specimen of this bird in the Aiken Collection, a male taken at Broadmoor Ranch, August 29, 1897.

Allen says that in 1871 it was "Frequent near Colorado City." This statement seems rather odd in view of the fact that the above mentioned specimen is the only one seen or taken in El Paso County since.

Calamospiza melanocorys. Lark Bunting.

Summer resident; common. Arrives usually early in May, about the 10th. It was reported by Scheutze April 10, 1910, and by Shaw April 15, 1912. Leaves in September.

A bird of the plains and open country, nesting on the ground, laying 4 or 5 unspotted pale blue eggs. When first arrived they are in flocks, the males paying active court to the gentler sex, and singing continually. In western Kansas Aiken found Lark Buntings very numerous and the notes on their habit of singing on the wing apply so well to them in Colorado they may well be quoted here: "The males are singing almost incessantly from daylight until 7 or 8 o'clock, and frequently throughout the day. They frequent open prairie without brush, but prefer cultivated districts where there is an early growth of weeds and grass. The male mounts into the air at an angle of about 60 degrees to the height of 15 or 20 feet, gives two or three broad flaps of his wings as he steadies, and then floats off to the ground, alighting 15 or 20 yards from where he started, and singing continuously, in one key as he rises, in another as he floats downward. Looking out over the prairie one see them in their conspicuous black-and-white dress going through this performance as far as the eye can discern.

At this time of the day (morning) females are not seen being probably on their nests, but during the heat of the day they are seen feeding along the road or making short low flights." This was May 24, 1900. He found full-fledged young at Ramah July 15, 1897.

Piranga ludoviciana. Western Tanager. "Louisiana Tanager."

Summer resident; common. Arrives May 10-15. Begins to leave early in September, but has been taken as late as the middle of October.

The Tanagers arrive from the south in small flocks of from 3 or 4 to 7 or 8, and in migration are found well out on the plains. While the majority pass on a good number remain to breed. They are largely birds of the foothills and the Divide, probably not breeding much above 8,000 feet, though Aiken saw one in the neighborhood of St. Peter's Dome, 8,700 feet, July 4, 1907. In summer they are confined almost exclusively to the pines. Keyser speaks of finding a nest in a pine tree at the entrance of Engelmann's Cañon near Manitou. While often seen in Monument Valley Park in May it probably does not breed there, not having been observed in the summer months. Aiken notes the call as *clit'-ic* or *crit'-ic,* uttered at intervals of one or two seconds.

Piranga erythromelas. Scarlet Tanager.

Rare. One was taken at Palmer Lake, May 17, 1902, by W. C. Ferrill. J. A. Jeancon reported seeing a considerable number at Palmer Lake, May 16 and 17, 1909, during a severe snowstorm.

Petrochelidon lunifrons lunifrons. Cliff Swallow. Eave Swallow.

Summer resident; common. Arrives the middle of May; leaves the last of August or early in September.

This species reaches a high altitude, at least in its search for insects, for it has been observed to above 13,000 feet. One of our most common swallows. It breeds in colonies about cliffs and buildings, on the latter under the eaves.

Hirundo erythrogastra. Barn Swallow.

Summer resident; not numerous. Usually arrives about May 1; has been seen as early as April 20, 1899. Departs the last of August or early in September.

Found over much of the County, but not nearly as common as the Cliff or Violet Green Swallows; perhaps the fourth in abundance of our swallows. Like the others it wanders above timberline in pursuit of insects.

Iridoprocne bicolor. Tree Swallow.

Summer resident; rare.

Allen noted a pair nesting in June on West Monument Creek. One of the rarest of our swallows, only a few seen. Aiken has noted a breeding colony at Divide Station, Teller County.

Tachycineta thalassina lepida. Violet-green Swallow.

Summer resident; common. Arrives about May 1; April 23, 1899, being the earliest date. Departs about September 1. Wetmore took two at Palmer Lake September 5, 1909.

This is the most abundant of our swallows; it seems to breed mostly in the mountains and foothills, nesting in hollow trees, and often using old woodpecker's holes. Allen noted it breeding in holes in the rocks at the Garden of the Gods in 1871, and the birds still continue to breed abundantly there. Like the other swallows in August the Violet-green begins to gather in flocks preparatory to the departure for winter quarters. For days we see them congregated on the telegraph and telephone wires, then some day they are gone and not seen again until the next spring.

Riparia riparia. Bank Swallow. Sand Martin.

Rare; Aiken mentions seeing it April 26, 1872. There are no records of its breeding in the County.

Stelgidopteryx serripennis. Rough-winged Swallow.

Summer resident; common. Arrives about May 10; departs with the other species.

This species, while fairly common, is somewhat locally distributed in the breeding season, owing to the comparative lack of suitable nesting sites. Full-fledged young of the year were taken along Monument Creek, north of Roswell, July 23, 1899, by Aiken.

Bombycilla garrula. Bohemian Waxwing.

Winter visitor; irregular; not seen at all many winters.

The first note we have of this species is January, 1872, when Aiken saw a flock in Barnes's Cañon, near Turkey Creek, and a note that Carter killed one on Pike's Peak the fall of 1871.

There are specimens in the Aiken Collection taken on Cheyenne Mountain, January and February, 1880. There were some around the winter of 1910-11, and they were in Colorado Springs, February 26, 1911.

Aiken noted at Salt Lake City, Utah, in 1895, that in the late afternoon the Waxwings, which had been about neglected orchards near the town feeding on the apples still hanging to the trees, began to fly in flocks up the cañons toward the mountains, evidently going to their roosting places in the green timber.

Bombycilla cedrorum. Cedar Waxwing.

"Noticed only two or three times and in the earlier part of the winter." Aiken List, 1872. 5 or 6 seen on Beaver Creek by Aiken, October 17, 1872. This was just over the line into Fremont County. Several were also seen by him just south of Colorado Springs, August 8, 1897.

Lanius borealis. Northern Shrike.

Winter visitor; common. Earliest date of arrival, October 17, 1874; latest spring date, April 9, 1899.

When one speaks of the Shrike as common it is not that they are so numerous, but because, though individually few, there are always some with us through the winter. It is usually to be seen perched on a tree or post, near brush frequently by sparrows or juncos, watching for a chance to get a meal. No doubt the bird also picks up a few mice, and an occasional insect. Aiken shot one flying with a large field mouse in its claws. One was seen in Monument Valley Park one November day tormenting a Magpie much as a Kingbird would. The Magpie was perched in a tree and the Shrike would fly at it and make it move to another place, and repeated these tactics until "Maggie" got disgusted and went away altogether. This Shrike was about the park from October 20 until November 17, 1912. A male was seen singing in the park November 1, 1913.

At Ramah, in March, 1899, Aiken saw this Shrike carry away a Horned Lark which he had just shot and killed. The Shrike pounced upon the lark and seized it by each shoulder with its feet, and then rose into the air and flew off with it against an exceedingly strong wind, the lark being held so that its wings were outspread beneath the body of its captor, thus helping to lift or support itself in the air.

Lanius ludovicianus excubitorides. White-rumped Shrike.

Summer resident; common. Rather irregular in arrival in spring, from March 30 to May 1, probably most of them come from the middle to the latter part of April. Most of them have left by October first, but a few linger somewhat later.

Mostly a bird of the plains and foothills, but at times ranges high in the mountains. Aiken once noted it above timberline at the head of Tennessee Gulch, Lake County.

This Shrike builds a bulky nest of small sticks, lined with wool and other soft material. Aiken found two nests at Ramah with 7 eggs in each, June 4-7, 1898. He saw old birds feeding young with grasshoppers at the same place, July 15, 1897, at which time 30 adults and young were seen. These birds are great destroyers of grasshoppers and other insects and probably do not kill as many birds as the larger species, though their actions and habits are in many respects the same. Scheutze reported seeing a pure albino of this species May 1, 1904, on the plains east of Colorado Springs. A Shrike with black crown was killed and mounted by the same party about June 1, 1907, but before it had been critically examined it was destroyed by a cat.

In reference to the black-headed Shrike Prof. Wells W. Cooke writes:

"There are about six species of shrikes in the world which have a black crown, but they are all African species, and since they are non-migratory the only way one of them could have gotten to Colorado would be as an escaped cage bird. So far as I know there is no European species of shrike that has the crown black; their shrikes are closely related to ours."

Vireosylva gilva swainsoni. Western Warbling Vireo. Swainson's Vireo.

Summer resident; common. Arrives about May 15 to 25; departs the last of August and early in September.

Breeds on the plains and in the mountains; Aiken noted it near St. Peter's Dome, and Keyser at Lake Moraine. Breeds in the trees near the streams, building a semi-pensile nest like other vireos on the lower branches. Aiken found a nest in Monument Valley Park in June, 1907.

Lanivireo solitarius cassini. Cassin's Vireo.

Rare; one taken at Palmer Lake, September 6, 1909, by Alex. Wetmore.

Lanivireo solitarius plumbeus. Plumbeous Vireo.

Summer resident; common. Arrives about May 16; departs early in September.

Frequents park-like areas with scattered pine, from the foothills to 9,000 feet. Aiken noted it at St. Peter's Dome July 4, 1907. Common on the Divide and along the foothills. On Turkey Creek he found the nests in small second growth pines, some as low as four feet from the ground. It has been found breeding on Cheyenne Creek at Ivywild.

Mniotilta varia. Black and White Warbler.

A single specimen of this warbler was taken by Aiken on Turkey Creek in the autumn of 1875, the only record for the County.

Protonotaria citrea. Prothonotary Warbler.

Rare; but one record for the County, a specimen taken between Palmer Lake and Monument, May or June, 1900, by B. G. Voigt, and recorded by Felger, Auk, XXIV, July, 1907, p. 342. Aiken has visited the locality indicated and found an extensive willow thicket flooded by beaver dams, producing quite suitable conditions for this species.

Vermivora virginiæ. Virginia's Warbler.

Summer resident; common. Arrives in May, earliest date May 2, 1872; most numerous about the 15th. Departs the last of August and early in September. At Palmer Lake, September 6, 1909, Wetmore took three and saw others.

A bird of the foothills, ranging in the breeding season to about 8,000 feet. In migration, especially in spring, it is

abundant along the valley streams in the trees and bushes. The males come first, but their mates are not long in following, and Aiken took a mated pair May 21, 1898, near Colorado City. It is a characteristic warbler of the foothills, and perhaps the most abundant of this group of birds in these localities. The first nest of this species known to science was found and described by Aiken. This was sunk in the ground in a tuft of bunch grass growing in a clump of oak brush, with the dead grass hanging over and completely concealing the nest, which was reached through a small round hole like a mouse hole through the protecting grass. This nest contained five fresh eggs, and was found about June 1, 1873. The species seems to nest exclusively about the oak brush.

Vermivora celata celata. Orange-crowned Warbler.

Common in migration. Arrives the very last of April, having been observed on the 27th and 28th of that month in different years.

This warbler is common about the trees and bushes of the valley streams and in the foothills during the first half of May, and is one of the very earliest of the warblers to arrive in spring, but there are no breeding records for this County. If Oberholser's subspecies *orestera* had been allowed by the A. O. U. our birds would belong to it, being intermediate in characters between *celata* and *lutescens*.

Vermivora peregrina. Tennessee Warbler.

Rare; but one record for the County, a juvenile male taken by Aiken, September 28, 1872. Aiken has found several near Limon, some distance easterly from our limits, and it is undoubtedly a regular migrant in the eastern parts of Colorado.

Compsothlypis americana usneæ. Northern Parula Warbler.

Rare, but one record for El Paso County, a male taken by Aiken, May 11, 1872, on Turkey Creek.

June 14, 1897, and for six successive days after that, Aiken observed in the top of tall cottonwoods at his home in Colorado Springs in the early morning a small grayish-olive warbler, with a conspicuous white band on the wing, which it seems must have been a Parula Warbler. It was seen again July 7; it is presumed to have had a nest in the neighborhood.

Dendroica aestiva aestiva. Yellow Warbler.

Summer resident; common. Begins to arrive the first week in May, the majority coming in the second week. Departs early in September.

This species is common almost everywhere in the County, at least where there is any sort of tree or brushy growth, and ranging up to above 9,000 feet. It builds its nest in the low bushes and thickets along the streams. Aiken found a nest with three eggs and one of the Cowbird near Bear Creek, June 17, 1898. June 3, 1913, a nest with 4 eggs was found near Ivywild. It is one of the most common summer birds in Monument Valley Park. Many of our breeding birds are very pale and several skins submitted to Mr. Brewster, were pronounced by him to be "nearly typical *sonorana*."

Dendroica coronata. Myrtle Warbler.

Migrant; not common. Arrives about May 1; earliest date April 17, 1907. There do not seem to be any autumn records.

Dendroica auduboni. Audubon's Warbler.

Summer resident in the mountains; common. Arrives the last of April and soon becomes abundant; the earliest record is April 16, 1872. Departs the last of September, the latest date being October 2, 1913.

This species breeds commonly in the mountains from about 8,000 feet to nearly 12,000 feet. Minot found a nest of the Audubon's Warbler at Seven Lakes, June 24, 1880, which he

describes as follows: "June 24, [1880] at Seven Lakes, I found four eggs almost ready to be hatched. These are curiously like a common type of the Yellow Warbler's, being greenish white, marked, chiefly about the crown, with olive brown and neutral tint and averaging about .70x.55 of an inch. The nest, composed of shreds and feathers, was built in a dead bare spruce, about twenty feet from the ground, compressed between the trunk and a piece of bark that was attached beneath and upheld above, where a bough ran through a knothole; so compressed that the hollow measures 2¼x1¾ and 1 1-3 inches deep. Such a position for the nest is not unusual, for I more than once saw the birds about dead timber."

Audubon's Warblers are usually common in the trees and bushes along the streams on the plains and in the foothills in the spring from their first arrival until the middle or latter part of May. A late valley record is one taken June 5, 1904, at Fountain, by Aiken. On the whole it is the most common warbler we have.

Dendroica striata. Black-poll Warbler.

Migrant; rare. The only records are of spring birds. Allen and Brewster noted it May 8 and 9, 1882, at Austin's Bluffs. Aiken took one May 18, 1872, on Turkey Creek; May 8, 1904, at Fountain; June 1, 1907, at Skinner's.

Minot, 1880, recorded it as "local summer resident about Seven Lakes." This record is open to question. Minot collected no specimens, and the locality is so far south of any other known breeding station of the species that the record had best be disregarded until substantiated by specimens actually taken.

Dendroica nigrescens. Black-throated Gray Warbler.

Local summer resident. Arrives about the first week in May, Aiken having taken his first specimen May 6, 1872.

As far as we know this species is confined in El Paso

County to the piñon and cedar region in the southwest corner, where they were observed all through the summers of 1872-73

Seiurus aurocapillus. Oven-bird.

Rare; but one record for the County, a female with ovaries well developed taken by Aiken at Ramah June 5, 1898. With one exception this is the only Colorado record.

Oporornis tolmiei. MacGillivray's Warbler.

Summer resident; common. Arrives the first or second week in May. Departs in September.

Breeds along creek bottoms from the lowest edge of the foothills and in the mountains up to above 9,000 feet. Shaw found it common in Crystal Park at 8,500 feet. It is common along the plains streams in the spring migration, and Aiken found it at Ramah, June 6, 1898, where it was very common as a migrant.

Geothlypis trichas occidentalis. Western Yellow-throat.

Summer resident; common. Arrives usually the first week in May; early records are April 13, 1882, and April 17, 1907. Departs in August and early September. The latest date is September 17, 1897.

Frequents the neighborhood of streams and ponds on the plains and along the foothills, rarely going above 8,000 feet, and breeding in damp thickets and swampy places. Aiken took a female near Bear Creek, July 25, 1897, which had an egg in the ovary. He noted a pair in Manitou Park, 8,500 feet, in June, 1905.

Icteria virens longicauda. Long-tailed Chat.

Summer resident; common. Arrives the first week in May. Leaves in September; latest date September 8, 1897.

Breeds along the valley streams to the foothills, but does

not penetrate into the mountains. A shy and elusive bird, though its song is continually heard in the early summer months. Olive Thorne Miller mentions finding a nest with three eggs near Camp Harding, on Cheyenne Creek; and Aiken mentions in notes young hatched June 25, 1872.

Wilsonia pusilla pileolata. Pileolated Warbler.

Summer resident in the mountains; common. Arrives about May 14. Leaves in September, latest date October 13, 1912.

This species is the western representative of the Wilson's Warbler. It is rather common during the spring migration in the thickets along the streams, found out on the plains as well as near the mountains, remaining until the last of May, but retires to the mountains to breed, and sometimes breeds in the Alpine willows above timberline. Minot found a nest at Seven Lakes which he describes as follows: "Here, June 22, [1880] I found a nest five fresh eggs. The nest was sunken in the ground, on the eastern slope or border of the swamp, at the end of a partly natural archway of long dry grass, opening to the southward, beneath the low, spreading branch of a willow. It is composed of loose shreds, with a nest lining of fine stalks and a few hairs, and with a hollow two inches wide and scarcely half as deep."

Setophaga ruticilla. Redstart.

Rare; not many records. Dates of arrival are May 17, 1905; May 14, 1898; May 18, 1882; May 21, 1872.

Allen saw it at Colorado City in 1871; he was there early in August. Almost all the birds which Aiken has taken or seen here have been immature males, in the plumage of the second year, and but one full plumaged male has been taken. There are no breeding records for the County.

Anthus rubescens. Pipit.

Summer resident at high elevations; common. Arrives on the plains the last of April and departs the last of September.

The Pipits breed mainly above timberline on the open grassy slopes, placing the nest in a hollow in the ground, often protected by a tuft of grass. They, however, in some instances breed below timberline on open ground. Aiken observed Pipits just below the lowest of the Seven Lakes in June. In migration this species often occurs on the plains in large flocks.

Cinclus mexicanus unicolor. Water Ousel. Dipper.

Resident on the streams in the mountains; not uncommon. In winter a few come somewhat lower down along the streams, outside the foothills.

Water Ousels are interesting birds, and if one takes into consideration the fact that the species apparently numbers but comparatively few individuals, might be termed common. It prefers the rapid mountain streams for a residence and only in winter does it come out of the foothills, and but few of the birds do this, most of them stay in the mountains the year round, always finging a little open water even in the coldest weather. It is regularly seen in winter in Ruxton Creek just below Lake Moraine, at 10,000 feet. One December afternoon I was there, it was cold and windy and I was resting in a sheltered place close to the creek, which had much fall at that place. An Ousel came to a rock a few feet away; the bird was down below the rushing water which splashed on it continually, and the rock was wet and slippery, but the Ousel did not mind a bit. Once it was down on a little twig which was just out of the water and all wet; it looked like a cold place to me, and I wondered how those delicate little feet could possibly keep from freezing. Then the bird flew upon the wet rock again and began to sing, and after singing a little there went to another rock and stood there bobbing and

singing away. (E. R. W.) The song is sweet and thrush-like, and heard under such conditions it sounds especially sweet.

The food consists mostly of aquatic insects, and one killed on Fountain Creek, near Colorado City, December 1, 1882, had a small fish in its stomach, too much digested to be identified.

The nest is a rounded mass of the green moss from the rocks along the stream, placed on or under a ledge of rock, often beneath a waterfall, and always near the water. Keyser mentions a nest with two young near Rainbow Falls, Ute Pass, and another nest found farther up the Pass. A nest was also found in South Cheyenne Cañon, near the lower of the Seven Falls. The nest under Rainbow Falls was occupied annually for many years, until the falls were destroyed by a cloudburst which washed away the rocks forming them. Olive Thorne Miller saw an adult in South Cheyenne Cañon feeding a young bird large enough to be out of the nest.

Near Rainbow Falls Aiken was once able to observe closely an Ousel feeding in the water. He says: "As I walked down the Ute Pass road I looked into the gorge below Rainbow Falls and saw a Water Ousel at the shore of the stream repeatedly dip into the water and return to rest on a certain stone at the water's edge. Its actions were unusual; I had noticed nothing like it before and was curious to observe more closely. So taking advantage of the moments when the bird was beneath the water I moved toward the spot and when it came to the surface I stood motionless. In this way I reached the stream and stood within two feet of the Ousel's perch without alarming him. He merely cocked his head and looked up curiously but gave me no further attention.

The stream at this place dashes noisily over rocks and boulders but on this side was a quiet pool. This was three feet or more across and seven or eight inches deep with a clean sandy bottom which was distinctly seen through the clear water, as were also circling fragments of drift brought

in by an eddy from the stream. When the Ousel was ready to go into the water it dove in head first and lit on the bottom of the pool where it walked or ran about as if on dry ground. It chased and seized in its beak certain small particles of the drift that were perhaps water insects or insect larvæ. The time spent under water was some seconds, perhaps a minute. When he was ready to come out for breath he walked over to his resting place, popped to the surface of the water like a bit of cork and stepped out perfectly dry onto the stone.

What a remarkable provision of Nature is this which enables a little song bird to float without effort upon the water's surface, or to sink at will and walk securely along the bottom beneath! The explanation, however, is not difficult. Its body plumage is long, dense, and impervious to water. Under ordinary circumstances, and particularly if floating, the feathers stand out loosely from the body and the outward bulk of the bird is great in proportion to its weight. Its bulk is lighter than the same bulk of water and it floats. But if its plumage and wings are tightly pressed against the body excluding all air, the bulk is reduced so that its weight is greater than the same bulk of water and the bird sinks."

Oreoscoptes montanus. Sage Thrasher. Mountain Mockingbird.

Migrant; not common. Arrives early in April, from the 7th to the 15th. There are no breeding records. The only autumn date we have, if it can be called such, is one seen by Aiken six miles north of Colorado Springs, July 25, 1898.

This bird is not at all common in El Paso. County, and is only seen during migration. In the breeding season it inhabits the greasewood and sage brush plains, of which there are none in the County. An occasional bird may be seen at the time of the spring snowstorms when they are driven from the mountains.

Fig. 42. *E. R. W., Photo.*
LONG-TAILED CHICKADEE.
Bison Reservoir, Teller County, Colo.

Fig. 43. *E. R. W., Photo.*
MOUNTAIN CHICKADEE.
Bison Reservoir, Teller County, Colo.

Fig. 44. *E. R. W., Photo.*
ROBINS AND NEST.
Colorado Springs.

Fig. 45. *E. R. W., Photo.*
YOUNG MOUNTAIN BLUEBIRD.
North Park, Colo.

Mimus polyglottos leucopterus. Western Mockingbird.

Summer resident; locally distributed. Arrives the first week in May; earliest date April 26, 1882, Allen and Brewster.

Mockingbirds are locally common in El Paso County; in the Fountain Valley, toward the Pueblo County line, there are many and Aiken found them rather abundant at Ramah, where, June 4-7, 1898, he found two nests and eggs. Speaking of their habits, his note book says: "The female bird is retiring and noticeably browner. The male bird, on the contrary, is much in evidence, taking extended flights across the open country and from one part of a grove to another, conspicuous from his brighter color and large white wing patches."

A year previous to this he was told of a pair coming to a ranch on the open prairie east of Colorado Springs. The ranchman set some branches from pine trees in the ground and the birds nested in one of these. When the five young were well grown they were put in a cage and were fed there by the mother until they could take care of themselves. One escaped from the cage and was followed off by the male bird, but the female remained to feed the caged birds.

The species is rare at Colorado Springs; instances are known, however, of its breeding in the city. In 1904 a pair of Mockingbirds nested in a tree beside the street on Wood Avenue. Though the tree was but a small one its foliage was so dense that the nest could hardly be seen, and would be unnoticed by the casual passerby. The bird was seen on the nest June 17. I went away a day or two after and was absent most of the summer, but on my return was told that a brood had been successfully raised. The last of May and early part of June the male bird was continually singing, being heard even in the night. Not another Mockingbird was seen in that vicinity until May 7, 1913, when a male was seen, but only on that one occasion. A few other cases have been known of its breeding in the city, and for two or more years in succession at the respective localities.

Dumetella carolinensis. Catbird.

Summer resident; common. Arrives from the 7th to the 14th of May. Leaves in September, the 16th being the latest sure date, though one was thought to have been seen October 2, 1913.

The Catbird is common in the thickets along the streams, but does not penetrate far into the foothills and mountains. There are many in Monument Valley Park. An occasion of special abundance was June 1, 1907, when Aiken estimated that he saw 100 at the Skinner Ranch.

Toxostoma rufum. Brown Thrasher.

Summer resident; not common. Arrives about the first week in May, from the 4th to the 14th.

The Thrasher is found along the valley streams and gulches but does not go far into the mountains. It is of rather retiring habits and so escapes observation, but at best it is not at all common in El Paso County. Aiken noted a brood of young at Ramah, July 15, 1897.

Toxostoma bendirei. Bendire's Thrasher.

But one record for the County, and possibly for the State, a specimen taken at Austin's Bluffs, May 8, 1882, by Allen and Brewster.

Salpinctes obsoletus obsoletus. Rock Wren.

Summer resident; common. Arrives about April 16-20, but does not become abundant until several days after. Latest autumn date, September 23, 1907.

Rock Wrens are common about rocky places, and are also found in the arroyos with steep banks on the plains. They reach an altitude in the mountains of some 9,000 feet. They breed wherever found, in holes in the banks or in crevices in the rocks. The song of the Rock Wren is singularly like that

of the Mockingbird; as might be supposed it lacks the power and volume of the larger bird's song.

Catherpes mexicanus conspersus. Cañon Wren.

Resident; not common.

The Cañon Wren is unquestionably a resident through the year in El Paso County, for it has been found in various months during the winter, and breeding in the summer.

Minot, June 8, 1880, found a nest near Manitou, which he described as follows: "The nest was in the roof of a cave, about ten feet from the ground, with an opening so narrow, vertically, that I could neither look in nor introduce my hand. Fortunately, however, the rock was so soft that I easily removed the bottom slab on which the nest rested. This, as one looks down upon it, suggests the Eastern Wood Peewee's. It is composed of twigs, stalks, and bits of leaves, surrounded by a few loose sticks, and thickly felted with, down silk, and a few feathers. The hollow is 2½ inches long, and scarcely half as deep. The eggs measured about .70x.50 of an inch, and are crystal white (rosy when fresh), sparsely speckled and spotted, chiefly about the crown, with medium dull brown."

In the summer of 1912 Lloyd Shaw found a pair nesting in the steep rocks at the Gateway of Crystal Park. One of the birds was seen July 19 carrying food to the young. The nest was located under an overhanging rock in the cliff and was inaccessible. Allen found the species in the Garden of the Gods in 1871, and he and Brewster found it there in 1882, also in North Cheyenne Cañon. Olive Thorne Miller found it in South Cheyenne Cañon, where it apparently had a nest in or near the Pillars or Hercules.

The Cañon Wren has a habit of creeping around among the rocks is such a fashion that when one gets just a mere glimpse of the creature he is just as apt to think it is a chipmunk as a bird.

Thryomanes bewicki bairdi. Baird's Wren.

But one record from El Paso County, a specimen taken by Aiken at Colorado Springs, May 1, 1879.

Troglodytes aëdon parkmani. Western House Wren.

Summer resident; common. Arrives the first week in May, earliest date April 24, 1898. Leaves in September, the latest date being September 25, 1907.

Probably found all over the County, ranging up to timberline, and abundant wherever found, and breeding everywhere. Aiken found a nest with 7 fresh eggs in a cavity in a rock ledge near Palmer Lake, June 26, 1907. Their favorite nesting places are natural cavities in trees or old woodpeckers' holes, but they will use almost any hollow they can find.

Telmatodytes palustris plesius. Western Marsh Wren.

Summer resident; not common.

Arrives in April. A Marsh Wren seen by Aiken near Skinner's April 16, 1899, was probably of this form. One was shot not far from the same locality by Allen and Brewster April 22, 1882. The scarcity of records is due to the scarcity of suitable ground in the vicinity of Colorado Springs. That it breeds in the County is only presumptive; there are no records.

Telmatodytes palustris iliacus. Prairie Marsh Wren.

Winter resident; moderately common in suitable localities. Aiken saw several at Skinner's, and took one, January 15, 1908, which was examined by Oberholser and referred to this subspecies. Probably all winter residents are visitors from the north and should be so classed.

Certhia familiaris montanus. Rocky Mountain Creeper.

Resident in the mountains; not common.

The Brown Creeper is not at all common in El Paso

County and it is rather unusual to run across one. It seems to be nearly confined to the mountains and foothills, but it has occasionally been seen within the city limits of Colorado Springs. When seen it is usually in company with the chickadees and nuthatches. It ranges as high as there is timber; was noted at Lake Moraine December 11, 1906.

Sitta carolinensis nelsoni. Rocky Mountain Nuthatch.

Resident in the mountains; common.

This representative of the White-breasted Nuthatch is frequently seen in the foothills and mountains, and is also common on the Divide. In winter it drifts somewhat farther out to the bluffs, and has also been seen in Colorado Springs. A pair seen at Buttes May 12-20, 1908, by Aiken, were thought to be breeding.

Sitta canadensis. Red-breasted Nuthatch.

Resident in the mountains; not common.

This is by far the least common of our three species of nuthatch, and sometimes a year or more goes by without seeing one, and again it may be seen rather frequently. It seems to be mainly a mountain bird, but Aiken noted it at Fountain June 5, 1904, and May 7, 1905; he also saw it at St. Peter's Dome July 4, 1907.

Sitta pygmæa. Pygmy Nuthatch.

Resident; common.

This little fellow is the most abundant of our nuthatches, seen in flocks when the others are seen singly. Like the others it is essentially a mountain bird, but in the winter wanders somewhat away from the foothills. It is found on the Divide and noted at Palmer Lake and Eastonville; also seen at Austin's Bluffs in winter. It frequents evergreen trees almost exclusively and is but rarely found in other kinds, and then

the evergreen are usually not far away. While it is often found associated with Chickadees and the other nuthatches occasionally good-sized flocks which seem to consist solely of this species are seen.

Bæolophus inornatus griseus. Gray Titmouse.

Found only in the cedar and piñon region in the extreme southwestern portion of the County, where it is resident, and was found by Aiken to be common in winter but scarce in summer. It was less common in December and January than in November and February, in which months they were most common. In winter they wander about in small flocks but in spring separate into pairs.

Penthestes atricapillus septentrionalis. Long-tailed Chickadee.

Resident; common.

This western subspecies of the common Chickadee of the East is found practically everywhere there are trees, except that possibly it does not range as high in the mountains as the Mountain Chickadee, though it has been seen at the Bison Reservoir, Teller County, 10,400 feet, but possibly an abundant food supply about a house might have had something to do with its presence there. It frequents willows and other deciduous trees. It nests in the valleys as well as in the hills and Aiken's notes contain the following description of a nest he found on the Fountain below Colorado Springs, May 6, 1899: "I saw one of the birds fly and disappear near a stump with something in its mouth. At first I discovered no hole but soon noticed a small one at the edge just inside the bark. Breaking away part of the bark I found a considerable excavation, about 10 inches deep, with the bird sitting closely at the bottom. A twig that I reached down to her she seized in her beak and allowed herself to be lifted by it nearly to the top. I was obliged to break away more bark to reach the

bird, took her in hand and then liberated her. The nest was but half finished, only a mass of inner bark strips, So I plastered the pieces of bark in place and left it."

While each of our species of chickadees is found in flocks associated with the nuthatches and an occasional creeper, yet they seem to prefer not to have much to do with each other and are not very often found in the same flock, though they do sometimes thus associate. At the Bison Reservoir above mentioned both species came about the house for the scraps thrown out.

Penthestes gambeli. Mountain Chickadee.

Resident in the mountains; common.

This species, easily distinguished from the preceding by the white stripe on the side of the head, seems equally common with it, but is confined to the mountains in the breeding season, though wandering just as much in winter. It has been known to nest at least as high as the Strickler Tunnel, 11,500 feet. Warren saw this species at Lake Moraine in January, March, September, and December, but did not see the other species at that place on any of his visits. Keyser saw a pair feeding young in the nest near the Half Way House. It prefers to frequent spruces and other coniferous trees.

Psaltriparus plumbeus. Lead-colored Bush-Tit.

Resident; locally common.

Like the Gray Titmouse this species is found about the piñons and cedars, which constitute its breeding range, but unlike the other it wanders away from those trees at times and is occasionally found along the lower edge of the foothills, and has been known on at least one occasion to come about houses at the edge of Monument Valley Park. Warren found a flock of 40 or 50 in the northern part of the Garden of the Gods in January, 1910. Aiken took a nest with five

eggs at Red Creek Cañon, May 10, 1876. C. N. Holden took young birds on Turkey Creek about July 12, 1872.

Regulus satrapa olivaceus. Western Golden-crowned Kinglet.

Winter resident; not common.

This species is found mainly in the mountains and foothills, and at the bluffs. We have no records of it along the valley streams. It ranges high in the mountains, Warren finding it at Lake Moraine in January, and Aiken found a small flock at Clyde, Teller County, January 12, 1908. It is sometimes found in flocks consisting of the one species, but is more often in company with chickadees and nuthatches.

Regulus calendula calendula. Ruby-crowned Kinglet.

Summer resident in the mountains; not uncommon. A spring and autumn migrant in the valley and on the plains, arriving early in April, and not all leaving until November.

This Kinglet breeds in the mountains from about 9,000 feet up, having been seen by various observers in the summer season, though no one has yet taken its nest in this region. The bird has something of a reputation as a songster, and the volume of the song is remarkable when the small size of the singer is considered. Aiken made the following note on its song at Divide, Teller County: "A Ruby-crowned Kinglet was singing vigorously from a large spruce tree. The song as I took it down after carefully listening is *Tu-u-u-u-u-u Widdie Widdie Widdie Widdie Widdie Widdie Widdie.* The whole uttered rapidly and in monotonous key except the last 'Widdie' which had rising inflection."

Polioptila cærulea obscura. Western Gnatcatcher.

Rare; but few records for the County. "Seen May 6, and killed May 7, 1872, on Turkey Creek. Rather common for a

few days." Aiken, in note book. One take by Aiken north of Roswell, May 22, 1904, is the only record for El Paso County besides the preceding. It has never been seen in the breeding season in the County though the nest was taken by Nash at Pueblo.

Myadestes townsendi. Townsend's Solitaire.

Resident; common.

The Solitaire is a breeder in the mountains at the higher altitudes, coming lower in winter and spreading all over the region. A solitary bird in summer, but sometimes they congregate in flocks of 20 or more in warm, sheltered cañons and gulches in winter. Early in 1911 Solitaires were seen in the residence portion of Colorado Springs several times, which is something unusual.

Solitaires descend from the mountains about September first, and soon become quite plentiful in the foothills. As the season advances they seek the warmer sheltered nooks and remain there through the winter, often in small scattered flocks. Aiken first found them in Barnes's Cañon, November 1, 1871, frequenting the cedars and piñons of the hillside. Their flight and habit of alighting on the topmost twigs likened them to bluebirds. They were feeding mostly on cedar berries, but on bright warm days were often noticed on the ground beneath a bush or tree in search of insect food. At this season they seemed in full song and their notes were varied and melodious and akin to such famous songsters as the Wood Thrush, Meadowlark and Oriole. Later they were less musical and late in April when they had separated in pairs singing had ceased. At about this date, unless detained by storms, they ascend the mountains where parent birds with flying young were seen late in July.

Hylocichla fuscescens salicicola. Willow Thrush.

Migrant; not common. Arrives May 15. We have no autumn records.

This is the least common of our thrushes with the exception of the Alaska Hermit Thrush. Henshaw, Allen and Keyser report it from the lower mountains, 8,000-8,500 feet.

Hylocichla ustulata swainsoni. Olive-backed Thrush.

Migrant; common. Arrives May 9-15, and is abundant the rest of the month.

At Calhan and Ramah, June 4-7, 1898, Aiken found this species very numerous, estimating that over 100 individuals were seen.

Hylocichla guttata guttata. Alaska Hermit Thrush.

Migrant; not common. Usually arrives the first week in May, earliest date April 20, 1907, at Red Rock Cañon.

Migrates through the lower foothills and on the plains; found by Aiken along Fountain Creek from the town of Fountain north, in the vicinity of Colorado City, and also taken at Limon, Lincoln County. This is a bird of somewhat different habits from our other thrushes, keeping more on the ground, and in its flights not rising so high in the air; also much less shy and more approachable.

Hylocichla guttata auduboni. Audubon's Hermit Thrush.

Summer resident in the mountains; common. Arrives early in May, earliest date April 13, 1882, Allen and Brewster. A common migrant along the foothills and on the plains.

This species breeds in the mountains from 8,500 feet up, for Shaw found it in Crystal Park at that altitude in summer and notes that their songs were very common in the evening. Keyser found a nest with 4 eggs near Lake Moraine, in the lower limbs of a spruce. Aiken's notes contain a reference

to a nest found on Mount Manitou, July 6, 1872, containing 4 young; this was in a tree 2½ feet from the ground. Warren observed it at Lake Moraine, September 2, 1905. Aiken noted it July 9 and 10, 1899, as common about Strickler Tunnel and at intervals down to the Half-Way House. His notes say: "Song not as musical close to as at a little distance. I am reminded by the song of a musician, idly striking chords on a harp and listening after each chord for the echoes to die away."

Planesticus migratorius propinquus. Western Robin.

Summer resident; common. A few frequently spend the winter. The first spring arrivals sometimes come as early as February 25, but they do not become common until some time in March, usually the first or second week. The majority leave in October.

As stated above a few Robins frequently winter with us. The winter of 1904-5 there seemed to be a good many about Colorado Springs, and they were often noted in the town from November through the winter months and until the spring migrants came to swell their numbers. One was seen January 20, 1905, in a sheltered gulch in the foothills at about 7,000 feet. They do not seem to be afraid of the cold for they have been seen in zero weather. Aiken saw Robins at the Strickler Tunnel, 11,500 feet, April 22-23, 1899, and was told they had just arrived.

This species is found all over the County, and as just stated, ranges high into the mountains, and breeds wherever found. About Colorado Springs they pair in April and build immediately. Monument Valley Park had many nests in 1913, 10 being discovered in a small area; some of the young had left the nest by June 1. A young bird which was banded in a nest May 27, 1913, flew through glass in a greenhouse of the Pikes Peak Floral Co., June 23, 1913, and was killed.

Sialia sialis sialis. Bluebird.

Rare; but one record for the County, and this was for many years the only record for Colorado. July 15, 1872, when C. N. Holden, Jr., was visiting Aiken at the Turkey Creek ranch, he took one specimen, an adult male.

Sialia mexicana bairdi. Chestnut-backed Bluebird.

Summer resident; common. Arrives the middle of March, leaves in October.

While this species is common almost everywhere in migration, though probably never ranging quite as high as the next species, it breeds mainly in the yellow pine region between 7,000 and 8,000 feet, where it outnumbers the Mountain Bluebird. July 17, 1899, on the Divide north of Peyton, Aiken saw 20 Chestnut-backed to 5 of the Mountain Bluebirds, and it is probably more numerous on the Divide than anywhere else in the County. The two species are sometimes found in mixed flocks in the spring, especially when the weather is stormy. The appearance on the plains of this Bluebird during the spring migration is but for a short time, as it goes into the mountains and onto the Divide by the first of April, but the storms which usually come early in May drive the birds down in small flocks which remain until the weather clears and the snow melts. At these times the birds often become much emaciated and some die from starvation, being unable to obtain food while the snow is on the ground.

Aiken found a nest on Turkey Creek, May 27, 1872, in a woodpecker's hole, with young half fledged.

Sialia currucoides. Mountain Bluebird.

Summer resident; common. Arrives from the first to the middle of March. The majority leave in October.

There are various December and January records, as well as February. It had just arrived at the Strickler Tunnel April

22-23, 1899. It is very generally distributed, breeding wherever found, on the plains as well as in the mountains to timberline. It often uses deserted woodpeckers' holes for nesting sites. Aiken found a nest with young in a woodpecker's hole on Turkey Creek, May 29, 1872. His notebook says it was seen occasionally (near ranch on Turkey Creek) throughout the winter of 1872-3, and that it was very common in January, 1873.

In the early days of Colorado Springs this Bluebird bred readily in houses put up for it, but nowadays it has no show against the omnipresent English Sparrow. Like the preceding species this Bluebird congregates in flocks at the time of the May storms.

ADDENDA

H. C. Oberholser in "A Monograph of the Genus *Chordeiles* Swainson, Type of a New Family of Goatsuckers," U. S. National Bulletin No. 86, 1914, has described a new subspecies of Nighthawk, *Chordeiles virginianus howelli*, and refers the Colorado bird to it. If the form proves to be a valid one our El Paso County Nighthawks should be known by that name.

Regarding two other species Mr. Oberholser has given us the following notes:

He informs us that he now considers all the Horned Larks breeding in Colorado, and most of the winter birds, to be *Otocoris alpestris enthymia*, the Saskatchewan Horned Lark, a race not as yet admitted to the A. O. U. Check-List.

He also finds that the Savannah Sparrows of Colorado are not *Passerculus sandwichensis alaudinus*, but *P. a. nevadensis* Grinnell, the Nevada Savannah Sparrow.

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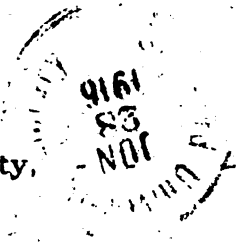

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SOIL FERTILITY.

By Guy Wendell Clark.

Part I—Historical.

Among the earliest attempts made to solve the problem of plant growth experimentally, was that made by Van Helmont,[1] who believed that he had proved by experiment that all of the products of vegetables were capable of being generated from water. Another of the early theories which created considerable interest when it was first published was that of Jethro Tull[2]. The chief value of Tull's contribution to agricultural science was the fact that he emphasized the importance of tillage operations by putting forward a theory to explain the fact that the more thoroughly a soil was tilled, the more luxuriant the crops would be. In 1804, De Saussure[3] made the most important contribution to science that had been received up to this time. He was the first to draw attention to the mineral or ash constituents of the plant, thus anticipating, to some extent, the "mineral theory" of Liebig. He showed that by far the largest portion of the plant's substance was derived from air and water, and that the ash portion was alone derived from the soil. This was the first statement, in any definite way, of the sources of the plant's food. During the years 1802–12, Sir Humphrey Davy[4] delivered a series of lectures before the English Board of Agriculture, in which he sums up and attempts to connect in a systematic manner, the practices and theories of that time. In 1834, Boussingault[5], a famous agricultural chemist, established the first real experiment station and began a series of brilliant chemical and agri-

[1]Jean Baptiste Van Helmont, Ortus medicinae, vel opera et opuscula omnia, published by his son, Frans Mercurius, in 1668.

[2]Jethro Tull, Horse-hoeing Husbandry, 1731.

[3]Theodore de Saussure, Recherches chimiques sur la végétation, 1804.

[4]Sir Humphrey Davy, Elements of Agricultural Chemistry, in a course of Lectures for the Board of Agriculture, London, 1813.

[5]Jean B. J. D. Boussingault, Traité d'économie rurale, 1844, translated by George Law, London, 1845. Also Agronomie, chimie agricole, et physiologie, seven vols., 1860–1884.

cultural experiments, the results of which have added much to agricultural science. He was the first observer to study the scientific principles underlying the system of crop rotation and was the first chemist to carry out experiments with a view to deciding the question of the assimilation of free nitrogen by plants. Even a brief sketch of the historical side of agricultural chemistry would not be acceptable if it failed to pay tribute to the great work done by Liebig[1], who earned for himself the title of "Father of Agricultural Chemistry." Liebig's claim to the rank of the greatest agricultural chemist of the time does not rest upon the number or value of his actual researches, but on the formative power he exercised in the evolution of science. His great mind was able to assemble the many isolated facts and to supply the necessary connections between them, the result being a large part of our modern agricultural chemistry. The indirect results of Liebig's work were as valuable as his real work in that they had the effect of giving a general interest to questions which, up to that time, had possessed only a special interest, and that for comparatively few. It was in Germany that Liebig's work manifested its greatest and most immediate results. Here many agricultural research stations were founded, the first being the now famous one of Möckern, near Leipzig, in 1851. Soon after Liebig's first work appeared, the second oldest experimental station was established at Rothamstead by Sir J. B. Lawes.[2] The fame of the Rothamstead experiments is now world-wide, and no single experiment station has ever produced such an amount of important work as has this splendidly equipped station at Rothamstead. Probably the greatest service the Rothamstead experiments have rendered agricultural chemistry have been the valuable contributions they have made to our knowledge of the function of nitrogen in agriculture; its relation, in its dif-

[1]J. von Liebig, Die Chemie in ihrer Anwendung auf Agrikultur und Physiologie, 1840. Also Die Grundsätze der Agrikultur-Chemie, 1855.

[2]Sir John Lawes; the Rothamstead station was started in 1843, although Sir John Lawes was engaged in field experiments ten years previous to that date. It was in 1843 that Lawes secured the services of Sir J. H. Gilbert, a distinguished chemist.

ferent chemical forms, to plant life, and the sources of the nitrogen found in plants.

It has long been believed that the constant cropping of soils resulted in the removal of such large quantities of the plant food constituents[1] that the subsequent decrease in crops was due to a dearth of these plant food constituents. This belief led to the early and rather extensive use of the various fertilizers, but the problem of keeping up soils and the reclamation of depleted lands by the use of fertilizers did not meet with success in many cases, failing to give the estimated results even when properly applied.

From a study of the ashes of plants we know that certain mineral substances are always present in plants and are essential to them as nutrients. It is evident that these mineral elements are derived from the soil but the amounts in which they may be present in the plants have not generally been found to bear any definite relation to the size of the crop, the fertility of the soil, or to its manurial requirements. It is often found that a poor crop has a higher percentage of ash and removes larger amounts of mineral matter from the soil than a good crop of the same variety. With the knowledge that plants obtain their necessary mineral nutrients from the soil, came the idea of "available plant food."[2] This idea, while it led to much work, had little practical value. It was, however, the guiding principle in most of the early chemical work done upon soils and undoubtedly gave us much valuable information.

It was hoped that by the various methods of analyzing soils the fertilizer requirements could be determined but, in general, the amounts of the several mineral fertilizers, which have been shown by experience to be necessary to produce marked or maximum differences in crop yield, are far too small to appear in the results of a chemical analysis. All soil extraction methods are purely empirical and have failed to a large extent. The one in which an extracting

[1]Phosphorus, nitrogen, potassium and calcium compounds are the most essential of the plant food constituents.

[2]That portion of the total amount of mineral nutrients which may be used by a crop or a succession of crops.

solution of a certain concentration is selected, so that the amount of mineral substances taken into solution would equal the amount, or a factor of the amount, that a crop would remove from the soil, has failed, because different crops, or the same crop, under slightly different conditions, remove not only different amounts, but vastly different relative proportions of mineral matter from the soil.

The idea that soils may contain substances which retard plant growth is not new but, until quite recently, has not taken any noticeable part in the modern literature of soil fertility. De Candolle's "Vegetable Physiology"[1] furnishes the most important consideration of the subject among the earlier writers. The theory was put forth that the grouping of naturally growing plants into what are now termed plant societies, might often be due to substances given off by the roots of plants inhabiting that area, the substances being injurious to other plants. De Candolle also reasoned that agricultural plants might produce root excretions which were injurious to the plants excreting them. At his suggestion Macaire[2] made a study of this question and published a review of this work up to 1831. In connection with this publication he carried on a number of original experiments and from the results of these De Candolle was led to consider that practically all plants give off excretions from their roots, the excretion being much more rapid in some forms than in others. He also expressed the belief that certain plants excrete from their roots substances which alter the soil in which the roots lie. With these ideas as a starting point, De Candolle formed a theory to explain the well-known fact that continuous cropping by the same plant species often resulted in a decreased growth, while a good growth of every crop might be obtained if proper rotation were resorted to. He distinguished between true exhaustion of the soil, in which case the soil may be considered as depleted in respect to the soluble salts necessary for plant growth, and what may be termed as false exhaus-

[1] A. P. De Candolle, Physiologie végétale, Paris, 1832.

[2] Macaire-Prinsep, Memoire pour servir à l'histoire des assolemens, Mém., de la soc. de physique et l'histoire nat. de Génève, 5, pages 282–302, 1832.

tion, in which case the cause of the poor crop is to be looked for in injurious excretions left by former crops. His theory of crop rotation was then, that crops, through their root excretions, render the soil unsuitable for the same or closely related plants but that these root excretions are harmless or even beneficial to distantly related plants. He also expressed the belief that careful experimentation would prove that plants of certain families give off excretions which are very marked in their toxic action and that those of other families are so feebly active in this respect that their effect is not noticeable. The above serves to clearly bring out the fact that to such a pioneer worker in the realm of plant physiology as De Candolle, the idea that infertility might be caused by the presence of toxic or deleterious substances in the soil, appeared to be the simplest and most direct means of explaining many of the known facts of plant distribution and agriculture. Since the work of Macaire and others, cited by De Candolle, is not to be considered as real evidence in the light of modern methods of experimentation, the theory of De Candolle comes to rest upon an inadequate foundation of actually observed facts.

There seems to have been no other serious discussion of this question until the publication of the work of Bedford and Pickering, carried on at the Woburn Experimental Fruit Farm[1], near Bedford, England. These reports[2] include accounts of the most interesting observations of the effect of one plant upon another through the apparent intervention of toxic substances. In the report for 1897 it was observed that when the soil surrounding their young apple trees was allowed to be occupied by weeds, or was sown to grass, the trees very soon showed a much poorer growth than that exhibited by other trees, around which the soil was properly cultivated, and that the effect was more pronounced in the case of grass than in that of weeds. Three years later, in 1900, the statement was made that

[1]Report of the Woburn Experimental Fruit Farm for 1897. An account of this work also appeared in the Jour. Roy. Agr. Soc. Eng., 64, pages 365–376, by Spencer U. Pickering.

[2]Reports of Woburn Experimental Fruit Farm, 1897–1905, by the Duke of Bedford and Spencer U. Pickering.

about the worst treatment to which young apple trees could be subjected was that of sowing the surrounding soil to grass. In their report for 1903 it was stated that the action of grass seemed to be just as harmful to old as to young trees and, that the injury produced was independent of variety or root stock. In view of all evidence, the authors conclude in this report that this action of grass is not merely a question of starvation in any form, nor of any simple modifications of the conditions, under which a tree could thrive, but that grass has some actively harmful effect upon the tree, the action being similar to direct poisoning.

That substances detrimental to plant growth might exist in the soil has also been indicated by the work of Woods[1], who, in a study of the mosaic disease of tobacco, found evidence for believing that this disease might be favored by the action of a substance apparently derived from the decay of tobacco roots in the soil.

In Bulletin 23, U. S. Department of Agriculture, Bureau of Soils, it was pointed out that the good or bad properties of certain agricultural soils were transmitted to their aqueous extracts and that differences in the content of mineral salts of these extracts did not explain the differences observed in cultures of wheat seedlings grown in them. These facts are assumed to favor the idea that soils experimented upon contained injurious substances which were sufficiently soluble in water to be present in the extract in amounts adequate to produce a marked effect upon the growth of wheat seedlings. Further evidence in this direction was brought forward in Bulletin 28, Bureau of Soils, where it was observed that the unproductiveness of a very poor soil from Takoma Park, Maryland, was largely due to the presence of injurious substances which checked the growth of plants. In the experiments on Takoma soil, certain cultivated plants, such as wheat seedlings, red and white clover, showed marked stunting, both of roots and tops. The work was done with aqueous extracts of the soil which

[1]A. F. Woods, Observations on the mosaic disease in tobacco, U. S. Department of Agriculture, Bureau of Plant Industry, Bul. 18, 1902.

were prepared by treating five parts, by weight, of soil with six parts of distilled water; this mixture was stirred for three minutes, allowed to settle twenty minutes, filtered and aerated, and was then used as the culture medium. By experiment it was found that the addition of stable manure, calcium carbonate, pyrogallic acid, ferric hydrate and carbon black,[1] all brought about a great improvement in the soil extract.

The so-called "acid soils" of the Eastern part of the United States have been found to turn blue litmus paper red and this has been interpreted by some as denoting the presence of soluble acids in these soils.[2] It was supposed by some workers in agriculture that the unproductiveness of many poor soils is due to acidity, such soils being spoken of as "acid" or "sour." It might then be supposed that the toxic substances considered are acid in their nature and that the toxic properties are due to the presence of free acids. It is possible, however, that the toxic bodies may be acid in their reaction and yet this acidity may not be the cause of their harmful effects upon the plants. For example, take the case of hydrocyanic acid, a very powerful poison. If the toxicity of this chemical, to plants and animals, were due to the hydrogen ion, that is to its acidity, this substance should not be more toxic than nitric or hydrochloric acids. Since it is so much more poisonous, it follows that the acidity of the compound is not the main factor in its toxic action but that the cyanogen is the active agent. This conclusion is also supported by the fact that potassium or sodium cyanide possess about the same toxic properties as the acid and yet have no free hydrogen ions. It thus appears possible that the toxic bodies of these poor soils may be acid in their reaction but that this acidity may have practically nothing to do with their toxic action. In a series of experiments[3], a number of acids were used; namely, nitric, sulphuric, hydrochloric, phosphoric, acetic and oxalic. The soil extracts were made just as acid as the soil with each of

[1]See Bulletin 28, U. S. Dept. Agr., Bureau of Soils, pages 15–24.
[2]Articles by H. J. Wheeler in the Bulletins of the Rhode Island Experiment Station.
[3]Bulletin 36, U. S. Dept. of Agr. Bureau of Soils, pp. 38–40.

the above acids and it was found that none of the acids had as marked a depressing effect upon growth as the toxic bodies of the soil extract. Some retardation was apparent in the case of all of the acids used, nitric showing the greatest retarding effect and oxalic the least. It is well to note that the acids of the soil are more apt to be of an organic than an inorganic nature, therefore the results just given should be considered as additional evidence that the toxic bodies are active through some other property than their acidity. A soil whose solution is perfectly neutral to litmus may exhibit this reaction through the difference in the absorptive powers of the soil and the paper.[1] The soil, on account of its high absorptive power for bases, removes the OH ions from the blue or nearly neutral litmus paper, leaving the H ions on the paper and thus causing it to be red. The only way of obtaining accurate evidence in this regard would be to work with an aqueous soil extract and a very sensitive solution of the indicator. It seems probable that where the soil is actually acid, the acidity is to be regarded rather as an indicator of the presence of injurious bodies, which may or may not be acid, than as evidence that free acids are the direct cause of the poor growth of crops. The term "sour soil," often spoken of by gardeners, probably refers to the smell of the soil and to its influence on plants rather than to any actual chemical property.

It was thought that the method of studying the soil extracts, rather than the soils themselves, would eliminate the influences of physical conditions. It therefore appeared that if a soil extract exhibited the unproductiveness of the soil from which it was prepared, the cause of the poor growth was due, to some extent at least, to the chemical properties of the soil solution, rather than to the physical properties of the soil.

There are various reasons advanced by the authors of Bulletin 36[2] why a nutrient medium may be unfit for the proper growth of plants, the most important of which are:

[1]Bulletin 30, Bureau of Soils, U. S. Department of Agriculture.

[2]Bulletin 36, U. S. Dept. of Agr., Bureau of Soils, by B. E. Livingston, assisted by J. F. Breazeale, C. A. Jensen, F. R. Pember and J. J. Skinner.

first, that it may be deficient in nutrient salts; second, that it may have too high a concentration of non-injurious dissolved substances; third, that it may contain toxic substances in such amounts that injury to the plant is actually brought about. In the experiments upon Takoma Lawn soil[1], the writers state that the unproductiveness of that soil, (and the soil solutions), could be due only to the third possible reason, because they obtained better growths in distilled water and in solutions, to which nutrient salts had been added, than from the soil extracts.

That infertility is not due to a lack of plant nutrients is also shown by the fact that highly enriched market gardens often become unproductive. The chemical analyses of such soils show that they are abundantly supplied with plant nutrients and yet there is a noticeable failure in the attempt to grow crops which at one time flourished on these soils. Experiments have been conducted[2] which afforded evidence that the growth of a second crop is not a question of plant nutrients and the same experiments agreed in indicating that the first crop leaves behind substances which are toxic to the following crops. There is not only a deleterious effect of a given plant upon its own kind but, in certain cases, upon different plants. Such successions are to be avoided in crop rotation as much as the growth of a single crop. It has been observed that rye grass and tares seem to poison wheat and that thistles seem to poison oats. Quite recently an antagonism between peach trees and several herbaceous plants, commonly used as cover crops in orchards, has been reported. It was found that young peach trees planted in large pots in which oats was also planted, shed their leaves and matured early. The foliage of these trees was not as abundant as that of other trees and before falling turned yellow. The trees grown in pots associated with tomatoes and potatoes were found to be next in order of injury but the yellow color of the foliage was not as marked as when

[1]Bulletin 28, U. S. Dept. of Agr., Bureau of Soils. Studies on the Properties of an Unproductive Soil.

[2]Bulletin 40, U. S. Dept. of Agr., Bureau of Soils. Some Factors Influencing Soil Fertility.

grown with the oats. Growth in pots with beans and crimson clover was not affected.[1]

It was found in the cases of the soil extracts studied that they were greatly benefited by the treatment with carbon black.[2] A comparison of the acidity of the treated and the untreated soil extracts showed no decrease in that property after the carbon treatment. Furthermore, all of the extracts studied as well as the soils themselves were noticeably improved by treatment with calcium carbonate. This salt being only slightly soluble in water, may be beneficial through its absorbing action or through the small amount of soluble substance added to the extract. The dissolved portion may show an accelerating action in three ways; first, through the nutrient value of the calcium, which is very improbable on account of the small amount of this element necessary for the development of most plant species; second, through some physiological property of this salt which counteracts the harmful effects of the poisons; third, through some effect of the calcium carbonate upon the toxic materials. It might be supposed, as has commonly been done by agriculturists working with lime, that it owes its beneficial effects mainly to its alkalinity which enables it to neutralize the acidity of the soil extract. It was shown that other alkalies, such as the hydroxide and carbonate of sodium, do not have the same beneficial effect as does the calcium carbonate. It is therefore evident that the action of this salt takes place through some other channel and also furnishes evidence that the toxic bodies are not mainly active through their acidity.

In the case of certain soils it has been shown that if the aqueous soil extracts are evaporated to dryness and charred to decompose the organic matter, and the residue then taken up again in distilled water, an increase in plant growth is obtained.[3] Since the inorganic salts, aside from nitrates and hydrated salts, are not changed by this treatment, the

[1]Hedrick, Proc. Soc. Hort. Sci., 1905, pp. 72–82.

[2]Bulletin 36, U. S. Dept. of Agr., Bureau of Soils, pp. 22–25. Also Bulletin 28, U. S. Dept. of Agr., Bureau of Soils, pp. 32–37.

[3]Bulletin 28, U. S. Dept. of Agr., Bureau of Soils, pp. 29–30.

indications are that the harmful properties of the extracts are due to organic substances.

Summing up the various lines of evidence on the nature of the toxic substances so far studied, it may be said that they appear to be slightly soluble in water; that in some soil extracts they are volatile with steam and in other extracts non-volatile; that they are usually accompanied by an acid reaction of the soil extract but the hydrogen ion does not appear to be the direct cause of their toxicity; and that they are probably organic in nature, being absorbed by finely divided, insoluble bodies, such as, ferric hydroxid, aluminum hydroxid, carbon black, etc.[1] The evidence concerning the origin of these toxic substances is very incomplete.

When the majority of soils are kept in good productive condition, by proper cultivation and the proper rotation of crops, it is not probable that toxic products will accumulate to an extent which would be harmful, but when one crop succeeds another of the same kind, these excretions may not be destroyed as rapidly as the best conditions for plant growth require. Especially is this the case if the soil be in a poor physical condition, unusually wet or dry, poor in organic matter, etc. If any of the toxic bodies in the soil result from the decay of roots it is evident that aeration would be beneficial, since it favors the destruction of organic matter by promoting the activities of the soil organisms and the processes of oxidation. In some types of soil, influenced perhaps by certain climatic environments, there appear to exist conditions which are unusually favorable to the rapid destruction of the toxic bodies; such soils, when planted year after year to the same crop, may not only maintain their original productive powers, but even increase them with continued cultivation.

PART II—EXPERIMENTAL.

As a part of the investigations which form the basis of this paper, two sets of experiments were conducted; one set

[1]Bulletin 36, U. S. Dept. of Agr., Bureau of Soils, pages 42 and 46.

dealing with the growth of wheat seedlings in the soils, see Tables 2, 3 and 4, and a second set dealing with the growth in soil extracts, see Tables 5, 6, 7 and 8. The experiments with the soils were carried on at one of the greenhouses of the Pikes Peak Floral Company, in Colorado Springs, Colorado. The wheat seedlings were grown in earthenware pots, two and one-half inches in diameter, four to seven seedlings per pot, and in shallow wooden trays, known to florists as "flats," holding about sixty pounds of soil and containing from eighty to one hundred seedlings. The experiments at the greenhouse were confined to two soils, designated as 3 and 4. Number 3 is a black, gravelly loam, found northeast of Colorado Springs, and is used by the Floral Company as a stock soil for their various plant beds. Number 4 is a sample of 3, in which carnations had been grown for more than one year.

Three crops of wheat seedlings were grown in each soil, using a new portion of 3 each time for control. The crops were grown from twenty-one to twenty-four days, at optimum water content and at an average temperature of 55° to 65° Fahrenheit. At the end of each growing period, the soil and plants were carefully removed from the pots and "flats," and the soil was crumbled and washed away from the roots and the average plant and root growth determined.[1] In each of the experiments the seedlings of the controls and of the pots and "flats" were grown under the same conditions of temperature, moisture and sunshine. The chemical analyses[2] showed that 4 possessed 1.66% more of acid soluble mineral constituents than 3, the percent of phosphoric acid (P_2O_5) being much higher. The high phosphorus content of 4 is explained by the fact that ground bone was added to the soil while growing carnations in it. The seedlings in the "flats" showed greater development of stems throughout the entire set of experiments than did those grown in the pots.

[1]In determining the plant and root growth the primary stem and the main root were measured. Growth expressed in inches and in percents of the growth of the control.

[2]For the chemical analyses of these soils see Table 1, page 627.

The following Table shows the constituents determined in the acid extracts of the four soils. The soils were extracted with hydrochloric acid, specific gravity 1.115, for seventy-two hours[1] at an average temperature of 70°–80° Centigrade. The methods of analysis were those adopted by the Associated Agricultural Chemists in 1907.[2]

TABLE 1.

CONSTITUENTS DETERMINED	SOIL 1	SOIL 2	SOIL 3	SOIL 4
Insoluble Residue.....	77.488%	72.487%	78.170%	76.510%
Ferric oxide.....	3.360	3.200	3.510	3.690
Aluminum oxide.....	4.740	6.920	6.080	7.620
Calcium oxide.....	3.320	2.530	1.510	1.360
Magnesium oxide.....	1.810	0.100	0.690	0.650
Sodium oxide.....	0.791	1.512	0.425	0.581
Potassium oxide.....	0.512	0.079	0.515	0.571
Phosphoric acid (P_2O_5)	0.255	0.249	0.279	0.410
Sulphur.....	0.177	1.040[3]	0.060	0.050
Nitrogen (total).....	0.232	0.116	0.238	....[4]

The results obtained from the experiments with the wheat seedlings in the soils, both in the pots and "flats," as shown in Tables 2, 3 and 4, indicate that the previous growth of carnations in 4 affected that soil in such a way that it yielded a much inferior growth of seedlings. It was also evident that the growth of one crop of wheat seedlings resulted in the formation of some substance, or substances, which retarded the growth of following crops, even when grown only from twenty-one to twenty-four days.

As to the causes of the effects produced by the growth of carnation plants upon wheat seedlings and also the effect of one crop of seedlings upon a following one, the writer has no experimental evidence to offer. That the effects were

[1]Official extraction period is ten hours.

[2]See Bulletin 107 (revised), U. S. Dept. of Agr., Bureau of Chemistry, Official and Provisional Methods of Analysis, pp. 13–20.

[3]High, contaminated by iron, determination not repeated.

[4]Determination not made.

due to the removal of the available supply of plant foods is not probable, for the plants were grown only a short time and chemical analyses, before and after three crops of seedlings were grown in the soil, gave the same percentages of the various constituents. The acid extractions of 3 and 4 show that 4 possesses 1.66% more of acid soluble material and indicated that the poor growth was not due to a dearth of the necessary plant foods.

The following tables indicate the results obtained in growing wheat seedlings in the soil.

TABLE 2. WHEAT SEEDLINGS GROWN IN POTS.

CULTURES GROWN IN	Number of days grown.	Number of plants studied.	Average plant length in inches.	Average per cent. of plant growth.	Average root length in inches.	Average per cent. of root growth.
Soil 3	24*a*	34	8.5	100.00	5.9	100.00
Soil 4	24	28	7.0	82.35	10.4	176.27
Soil[4] 1	24	8	4.7	55.30	4.6	77.96
Soil[1] 3	23*b*	21	9.6	100.00	7.3	100.00
Soil[2] 3	23	21	8.7	90.62	8.7	119.17
Soil[2] 4	23	24	8.1	84.38	9.1	124.66
Soil[1] 3	21*c*	12	7.8	100.00	6.9	100.00
Soil[3] 3	21	12	6.9	88.46	11.3	163.76
Soil[3] 4	21	11	6.6	84.36	11.5	166.66

[1]Virgin soil, fresh sample used each time,—controls.

[2]Second crop of seedlings in the same soil.

[3]Third crop of seedlings in the same soil.

[4]The physical condition of this soil was such that it packed very solid and baked on top. Only the one attempt made with the seedlings in this soil.

*a*Grown from February 2 to 26, 1914.

*b*Grown from February 26 to March 21, 1914.

*c*Grown from March 21 to April 11, 1914.

TABLE 3. WHEAT SEEDLINGS GROWN IN "FLATS."

CULTURES GROWN IN	Number of days grown.	Number of plants studied.	Average plant growth in inches.	Average per cent. of plant growth.	Average root growth in inches.	Average per cent. of root growth.
Soil 3.....	24*a*	36	10.0	100.00	4.5	100.00
Soil 4.....	24	37	7.8	78.00	6.0	133.33
Soil[1] 3.....	23*b*	33	12.2	100.00	4.4	100.00
Soil[2] 3.....	23	33	11.5	94.26	5.0	113.63
Soil[2] 4.....	23	32	8.0	65.57	6.0	136.36
Soil[1] 3.....	21*c*	22	8.7	100.00	4.1	100.00
Soil[2] 3.....	21	10	6.9	79.31	4.8	117.07
Soil[3] 4.....	21	10	5.4	62.05	4.4	107.31

TABLE 4.

Soil 3.....	24*a*	36	10.0	100.00	4.5	100.00
Soil 4.....	24	37	7.8	78.00	6.0	133.33
Soil 3.....	47*d*	15	17.4	100.00	4.6	100.00
Soil 4.....	47	14	14.4	82.76	4.3	93.48
Soil 3.....	68*e*	14	24.0	100.00	7.0	100.00
Soil 4.....	68	9	15.6	65.00	5.0	71.43

Much work has been done by the Bureau of Soils, of the U. S. Department of Agriculture, in attempting to show that plants secrete toxic substances, of an organic nature, which have a retarding effect upon plant growth[4]. A num-

[1]Virgin soil, fresh sample used each time, controls.
[2]Second crop of seedlings in the same soil.
[3]Third crop of seedlings in the same soil.
[4]See Bulletins 23, 28, 36, 40, U. S. Dept. of Agr., Bureau of Soils.
*a*Grown from February 2 to 26, 1914.
*b*Grown from February 26 to March 21, 1914.
*c*Grown from March 21 to April 11, 1914.
*d*Grown from February 2 to March 21, 1914.
*e*Grown from February 2 to April 11, 1914.

ber of organic substances have been isolated from soils and some experiments conducted to ascertain their effects upon growing plants.[1] The idea that substances, having a deleterious effect upon plant growth, are produced in the soil, seems plausible, but the theory that these substances are the result of plant excretion, does not seem to be acceptable, nor is it sufficiently supported by experimental evidence. In some cases we are led to believe that harmful substances are produced in the soil by the decay of plant roots and we may, in the years to come, find conclusive evidence that some plants do secrete substances, toxic to themselves and to closely related plants, but does it not seem more probable that the many kinds of soil organisms might play a more important part than either of the above, in the formation of complex organic substances, some of which are toxic to the various forms of plant life? It has been found[2] that the use of certain volatile antiseptics, such as toluene and chloroform, improve the productiveness of some soils. Partial sterilization by heating the soil has also given some beneficial results.[2]

Along this same line, L. H. Bolley[3], in speaking of soil sanitation with regard to certain cereal crops says: "Our older wheat soils are 'sick' in large areas in exactly the same sense as certain cotton lands are sick with root rots * * * ; in the same sense as old potato lands which produce rot and scab; in the same sense as the Germans recognized when they spoke of flax being a bad crop to raise because it produced 'Bodenmuedigkeit,' 'flax-sick' conditions. I am now able to recognize such wheat-sick areas * * * . How many distinct parasitic organisms it takes to make a typical wheat-sick soil, we cannot yet affirm, but our experiments are sufficiently extensive for us to state that at least five such parasites are persistent internally in most seed wheat, parasites which enter the

[1]See Bulletin 88, U. S. Dept. of Agr., Bureau of Soils; also see an article by O. Schreiner, in Science, 36, pp. 577-587. Same in Circular 74, U. S. Dept. of Agr., Bureau of Soils, 1913.

[2]A. D. Hall, Nature, 89, 1912, pp. 648-651.

[3]L. H. Bolley, North Dakota Agricultural College, Science, 32, 1910, pp. 529-541.

seed before it matures and which are carried over to the next generation * * * . All of these types of diseased grain breed true, that is, a diseased grain will carry diseases to the soil, * * * and the disease will be manifested in the seed of the progeny, and will persist in the soil so as to attack the following crop of wheat. These conditions may be bettered by seed and soil sterilization but the methods are not applicable to farm operations. Large areas of the world's wheat soils are not depleted chemically but rather contaminated with many diseases that wheat is heir to, and a number of these diseases are transmissible to nearly related crops."

The soil extracts used in the experiments were prepared by treating two hundred parts, by weight, of soil with five hundred parts of carbon treated[1] hydrant water; this mixture was stirred five minutes, allowed to settle twenty minutes and filtered through a thick layer of finely shredded asbestos. This solution, after shaking several minutes to aerate, was placed in salt-mouth, glass jars of about eighty cubic centimeters capacity. Corks, with suitable notches for the plants, were fitted closely so that practically all loss of moisture was that of plant transpiration. (There was undoubtedly loss by evaporation but the jars had the same sized openings and the corks were fitted in the same way to all.) Three wheat seedlings of uniform size were placed in each of the jars, which were then wrapped in black paper to protect the roots from strong sunlight. Two and three jars were prepared from each extract and each jar designated as a "culture." After weighing at room temperature, the jars were placed in a sunny room and kept at a temperature averaging 55°-70° Fahrenheit for eleven to sixteen days. At the end of this time the jars were again weighed, the transpiration determined, and the length of the primary stem and root determined. (By transpiration is meant the amount of water given off by a plant or a number of plants.)

The wheat seedlings used in these experiments were sprouted on floating disks, of paraffined iron wire, until the

[1]In treating the water with carbon black, ten grams of carbon were used for each litre of water; this solution was stirred five minutes and filtered at the end of thirty minutes.

first leaf broke through the sheath, fresh water being added every twenty-four hours.

The soil extracts were neutral to litmus and methyl orange but faintly acid to phenolphthalein. No change could be determined in their reaction after the seedlings had been grown in the extracts, eleven to sixteen days.

The chemicals used were of the very best quality and every precaution was taken to see that they were free from impurities. In testing the carbon black it was found to contain .118% ash, which proved to be oxides of iron and aluminum.

The problem of obtaining distilled water suitable for plant culture is one which remains to be solved. In the literature upon this subject there seems to be wide differences of opinion as to the cause of the apparent toxicity of distilled water for plants. Lyon,[1] in a study of distilled water and its toxic properties, at the Wood's Hole Experiment Station, expressed the opinion that the toxicity observed in his experiments might be due to the presence of traces of ammonia.

The hydrant water in Colorado Springs, Colorado, contains forty to fifty parts per million of solid matter. The average ammonia content is .0005 parts per million. The water distilled from potassium dichromate and sulphuric acid was found to contain .00013 parts of ammonia per million and the hydrant water after carbon treatment contained .00044 parts of ammonia per million. Since the hydrant water and the carbon treated hydrant water produced better plant growth than did the distilled water, it does not seem possible to attribute the inferior growth in the distilled water to the presence of ammonia.

The results obtained from the work with the soil extracts were; first, that ordinary hydrant water was a better medium for the growth of wheat seedlings than distilled water, also that carbon treated hydrant water was a better medium for plant growth than carbon treated distilled

[1]E. P. Lyon, A Biological Examination of Distilled Water, Biol. Bull. 6, 1904.

water;[1] second, that water, in contact with sprouting wheat for twenty-four hours, yielded the poorest growth obtained and that the above solution was not materially benefited by carbon treatment nor by five minutes boiling.[2] No other satisfactory results were obtained from the study of the soil extracts, for under the same conditions, vastly different figures for transpiration, plant and root growth, were obtained with the different sets of cultures. As a result of the experiments with the soil extracts, it would seem that to study the fertility of soils by this method, the experiments must be conducted for a longer period of time. E. J. Russel,[3] in discussing the experiments of the U. S. Department of Agriculture, Bureau of Soils[4], makes the point that the experiments were not conducted for a sufficient length of time and, that even if it were proven that the wheat seedlings secreted toxic substances, there were no reasons why it should be assumed that such would be the case with mature plants. As is shown in Table 4, page 629, some of the wheat seedlings were grown for 68 days and still the retarding effect of the carnation soil on the wheat seedlings was clearly shown.

In conclusion, the writer wishes to make acknowledgment to the many writers on agricultural chemistry, both to the writers of articles appearing in the current scientific papers and to those who have published their writings in book form, for the many ideas gained from them. Wherever possible, full reference has been made in the footnotes to the source of the quoted article. No startling claims are made in this paper but the writer hopes to have indicated, by experiments with the soils, that the growing of carnation plants in a soil for a considerable length of time, does result in the formation of substances which retard the growth of other plants, and that the present plan of using soil extracts as a means of determining the productiveness of soils does not seem to yield any definite or valuable results.

[1]See Table 5, page 634, and Table 6, page 635.

[2]See Table 6, page 635.

[3]E. J. Russel, of Rothamstead Experiment Station, "Alleged excretion of toxic substances," Nature, 78, 1908, pp. 402–3.

[4]Previously mentioned in the historical part of this paper, pp. 615–625.

TABLE 5. WHEAT SEEDLINGS GROWN IN SOIL EXTRACTS.

CULTURES GROWN IN:	Number of days grown.	Number of cultures studied.	Average plant growth in inches.	Average per cent. of plant growth.	Average root growth in inches.	Average per cent. of root growth.	Average grams of transpiration.	Average per cent. of transpiration.
Hydrant water[1]	12*a*	2	3.8	100.00	4.8	100.00	13.52	100.00
Distilled water[2]	12	2	3.3	86.84	0.8	1.67	6.83	50.51
Distilled water, plus Aluminum hydroxide[3]	12	2	3.8	100.00	7.2	150.00	16.74	123.81
Distilled water, plus ferric hydroxide[3]	12	2	4.2	110.52	6.9	143.75	11.34	83.87
3 Extract[4]	12	2	4.6	121.05	5.7	118.75	18.44	136.39
3 Extract,[4] plus ferric hydroxide[3]	12	2	4.8	126.31	7.9	164.58	25.64	189.64
4 Extract[4]	12	2	4.1	108.00	7.6	158.33	15.25	112.79
4 Extract,[4] plus ferric hydroxide[3]	12	2	4.3	113.16	7.0	145.83	18.11	133.95
4 Extract,[4] plus Aluminum hydroxide[3]	12	2	4.2	110.52	6.1	127.08	18.92	140.00

[1]Hydrant water, from city main—Controls.
[2]Distilled from sulphuric acid and potassium dichromate, in Jena glassware.
[3]All salts added in the ratio of 100 parts per 100,000.
[4]Two crops of seedlings grown in these soils previous to preparation of extracts.
*a*Grown from March 22 to April 3, 1914

TABLE 6. WHEAT SEEDLINGS GROWN IN SOIL EXTRACTS.

CULTURES GROWN IN:	Number of days grown.	Number of cultures studied.	Average plant growth in inches.	Average per cent. of plant growth.	Average root growth in inches.	Average per cent. of root growth.	Average grams of transpiration.	Average per cent. of transpiration.
Hydrant water, carbon treated[1]	14*a*	2	4.1	100.00	8.5	100.00	13.70	100.00
Distilled water, carbon treated	14	2	3.9	95.12	4.7	55.29	11.66	85.11
1 Extract	14	3	4.6	112.19	6.3	74.11	27.05	197.44
2 Extract	14	3	4.6	112.19	6.7	78.82	20.74	151.38
2 Extract, plus chromium hydroxide[2]	14	2	4.7	114.63	6.9	81.17	17.79	129.85
Solution from sprouting wheat[3]	14	2	3.2.	78.05	....*b*	....	4.42	32.26
Above solution[3], carbon treated	14	2	3.4	82.92	....*b*	....	5.02	36.64
Sprouting solution[3], boiled five minutes[4]	14	2	3.1	75.61	....*b*	....	4.20	29.34

[1]Controls.
[2]The chromium hydroxide added in ratio of 100 parts per 100,000.
[3]Water in which wheat had been sprouting 24 hours.
[4]One hundred cubic centimeters taken, distilled water added to make up to that volume after boiling.
*a*Grown from March 25 to April 8, 1914.
*b*Practically no root development, plants very inferior in every way. No measurements made.

TABLE 7. WHEAT SEEDLINGS GROWN IN SOIL EXTRACTS.

CULTURES GROWN IN:	Number of days grown.	Number of cultures studied.	Average plant growth in inches.	Average per cent. of plant growth.	Average root growth in inches.	Average per cent. of root growth.	Average grams of transpiration.	Average per cent. of transpiration.
Hydrant water, carbon treated[1]	12*a*	2	4.4	100.00	6.8	100.00	16.42	100.00
Distilled water, carbon treated	12	2	3.8	86.36	2.4	35.29	7.86	47.86
1 Extract, plus aluminum hydroxide[2]	12	2	4.0	90.90	4.3	63.23	8.20	49.93
3 Extract, (of the Virgin soil)	12	2	5.9	134.09	4.8	70.59	18.16	110.53
3 Extract[3]	12	2	5.2	118.18	4.6	67.64	25.77	156.94
3 Extract,[3] plus ferric hydroxide[2]	12	2	4.6	104.54	6.3	92.64	19.33	117.72
3 Extract,[3] plus ferric oxide[2]	12	2	4.3	97.72	3.9	57.35	13.91	84.71
3 Extract,[3] plus barium hydroxide[4]	12	2	4.3	97.72	3.6	52.94	13.66	83.19
4 Extract,[3] plus barium hydroxide[4]	12	2	3.3	75.00	1.4	20.58	3.79	23.08

[1]Controls.

[2]Salts added in ratio of 100 parts per 100,000.

[3]All extracts of 3 and 4 made from soil in which three crops of seedlings had been grown.

[4]The barium hydroxide extracts had an alkalinity equivalent to .312 mgr. sodium carbonate, per cubic centimeter.

*a*Grown from April 12 to April 24, 1914.

TABLE 8. WHEAT SEEDLINGS GROWN IN SOIL EXTRACTS.

CULTURES GROWN IN:	Number of days grown.	Number of cultures studied.	Average plant growth in inches.	Average per cent. of plant growth.	Average root growth in inches.	Average per cent. of root growth.	Average grams of transpiration.	Average per cent. of transpiration.
Hydrant water, carbon treated[1]	16*a*	2	4.7	100.00	7.5	100.00	16.98	100.00
1 Extract	16	2	5.7	121.27	6.1	81.33	15.04	88.57
1 Extract[2]	16	2	4.3	91.49	6.2	82.66	9.43	55.53
1 Extract, plus chromium hydroxide[4]	16	2	5.3	112.76	4.0	53.33	10.40	61.25
1 Extract, plus ferric hydroxide[4]	16	2	4.2	89.36	3.6	48.00	6.44	37.92
2 Extract	16	2	5.0	106.38	4.0	53.33	11.10	65.37
2 Extract[2]	16	2	5.0	106.38	6.2	82.66	14.43	84.98
2 Extract, plus aluminum hydroxide[4]	16	2	4.6	97.87	5.0	66.66	12.74	75.03
2 Extract, plus ferric hydroxide[4]	16	2	5.1	108.51	4.9	65.33	12.62	74.32
3 Extract (from Virgin soil)	16	2	6.7	142.55	3.0	40.00	23.91	140.78
3 Extract,[3] plus aluminum hydroxide[4]	16	2	5.0	106.38	4.0	53.33	11.23	66.13
4 Extract,[3] plus chromium hydroxide[4]	16	2	4.3	91.49	4.5	60.00	13.04	76.79

[1]Controls.
[2]Second crop of seedlings grown in the same extract.
[3]Extracts prepared from soils in which three crops of wheat seedlings had been grown.
[4]Salts added in the ratio of 100 parts per 100,000.
*a*Grown from April 25 to May 10, 1914.

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ON NON-RULED OCTIC SURFACES WHOSE PLANE SECTIONS ARE ELLIPTIC

—BY—

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ON NON-RULED OCTIC SURFACES WHOSE PLANE SECTIONS ARE ELLIPTIC

By Charles H. Sisam

1. The genus of the plane sections of a non-ruled surface of order greater than four has been shown by Picard* to be at least equal to unity. Castelnuovo has shown† that, if the genus of the plane sections does not exceed two, the surface is rational. It follows further, from results obtained by del Pezzo‡ that, if the rational surface is of order eight and is intersected by a generic plane in an elliptic curve, it belongs to one of two types. Those of the first type can be birationally represented on a plane in such a way that the plane sections correspond to a linear system of quartic curves having two fundamental double points. They are characterized by the property that two conics which lie entirely on the surface pass through each point of the surface. The surfaces of this type were discussed by the author in an article in the Quarterly Journal of Pure and Applied Mathematics, Vol. 47 (1916). They will not be considered further here. The surfaces of the second type can be represented on a plane in such a way that the plane sections correspond to a linear system of cubic curves through a fixed point P. It is the purpose of this paper to point out the fundamental properties of the surfaces of this second type.

2. If we take the point P as the vertex (0, 0, 1) of the triangle of reference in the representative plane, the parametric equations of the surface take the form

$$x = f_i(\lambda) = \sum_{\substack{j,k,l=1,2,3 \\ i=1,2,3,4}} a^{(i)}_{jkl}\,\lambda_j\,\lambda_k\,\lambda_l \qquad (1)$$

with the restriction that $a^{(i)}_{333} = 0$.

3. To the directions through the point P = (0, 0, 1) correspond points on a line g on the surface defined parametrically by the equations

*Crelle's Journal, Vol. 100, pg. 71.
†Rendeconti dei Lincei, Series V, Vol. 3.
‡Rendiconti de Palermo, Vol. 1.

$$x_i = a^{(i)}_{133}\lambda_1 + a^{(i)}_{233}\lambda_2 \qquad i=1,2,3,4$$

The existence of such a line g on the surface may be considered as characterizing the surfaces of the second type, since every non-multiple curve on a surface of the first type is of even order (cf. the author, loc. cit., pg. 57).

4. To a curve in the λ-plane which is of order m and has an m′-fold point at P there corresponds on the surface a curve of order

$$n = 3m - m' \qquad (2)$$

as may be seen by considering the equation of this curve as simultaneous with an equation (1).

It follows at once that there are no simple right lines, other than g, on the surface. For, since $m' = m$, we would have, for the curve corresponding to such a line, $2m = 1$, which is impossible, since m is a positive integer.

The conics on the surface ($n = 2$) are defined by putting $m = m' = 1$. These curves on the surface thus constitute a pencil corresponding to the pencil of right lines through P.

The cubic curves on the surface constitute a linear system of two dimensions corresponding to the right lines in the λ-plane.

There are no non-composite simple quartic curves on the surface since the equation $3m = 4 + m'$ cannot be solved in positive integers with $m' < m$.

5. *The genus of a non-multiple curve of order n on the given surface cannot exceed the greatest integer in*

$$\frac{(n-4)^2}{16}$$

Since the given curve is in (1, 1) correspondence with a curve in the λ-plane which is of order m and has an m′-fold point at P, its genus is equal to that of the latter curve and does not exceed

$$\frac{(m-1)(m-2)}{2} - \frac{m'(m'-1)}{2} = 3mn + 1 - 4m^2 - \frac{n(n+1)}{2}$$

The maximum value of this expression is $\frac{(n-4)^2}{16}$

If n is not of the form $8n'+4$, the limit stated in the above theorem is actually attained for all values of n. If $n=8n'+4$ the limit is too large by unity.

6. The equation of the cubic curve in the λ-plane corresponding to the section of the surface by the plane whose co-ordinates are (u_1, u_2, u_3, u_4) is, from (1),

$$u_1 f_1(\lambda)+u_2 f_2(\lambda)+u_3 f_3(\lambda)+u_4 f_4(\lambda)=0 \quad (3)$$

If we form the invariants S and T for this cubic, we determine the equations of two surfaces $S(u)=0$ and $T(u)=0$, of class four and six respectively, enveloped by the planes which intersect the given surface in curves for which the corresponding invariants are zero. The stationary planes, which intersect the surface in cuspidal curves constitute the system of planes tangent to both of these surfaces.

The condition that a plane intersects the surface in a curve whose absolute invariant has a given value k is that the plane touches the surface of class twelve defined by the equation

$$S^3(u)-k\,T^2(u)=0 \quad (4)$$

In particular, if $k=6$, so that the section is rational, then (4) is the equation of the surface in plane co-ordinates.

7. The parametric equations of the tangent plane at the point whose parameters are $(\lambda_1 \lambda_2 \lambda_3)$ can be obtained at once by imposing the condition that the cubic (3) has a node at this point. The condition is

$$\begin{vmatrix} x_1 & x_2 & x_3 & x_4 \\ \frac{df_1}{d\lambda_1} & \frac{df_2}{d\lambda_1} & \frac{df_3}{d\lambda_1} & \frac{df_4}{d\lambda_1} \\ \frac{df_1}{d\lambda_2} & \frac{df_2}{d\lambda_2} & \frac{df_3}{d\lambda_2} & \frac{df_4}{d\lambda_2} \\ \frac{df_1}{d\lambda_3} & \frac{df_2}{d\lambda_3} & \frac{df_3}{d\lambda_3} & \frac{df_4}{d\lambda_3} \end{vmatrix} = 0 \quad (5)$$

From this equation we obtain the parametric equations of the surface in plane co-ordinates in the form

$$u_i = J_i(\lambda) \qquad i = 1, 2, 3, 4$$

wherein $J_i(\lambda)$ is the co-factor of x_i in equation (5).

The curves $Ji(\lambda) = o$ are of order six. They have the fundamental point P (Art. 3) as a double point and, since the surface is of class twelve, they have in common twenty other fixed points $P'_1, P'_2, \ldots, P'_{20}$. The curves (3) that pass through one of these twenty points have a common tangent at the point. These points thus correspond to the pinchpoints on the nodal curves.

The curves of the linear system $\Sigma\, x_i J_i(\lambda) = o$ correspond on (1) to the system of curves (of order sixteen) of tangency of the tangent cones to the given surface from the points of space. They are of genus nine, which is the genus of the tangent cone.

8. If we form the system of Jacobians of the bundles of curves in $\Sigma\, x_i J_i(\lambda) = o$, we obtain* the system of curves (3), together with a fixed curve $C(\lambda) = o$, which is the locus of points at which a curve of (3) has a cusp and corresponds to the parabolic curve on the given surface.

The curve $C(\lambda) = o$ is of order $3(6-1)-3 = 12$. It has a fourfold point at P and a double point at each of the twenty points P'. The parabolic curve is thus of order thirty-two. It has a double point at each pinchpoint, intersects the right line g in four points and each conic on the surface in eight points. Its genus, which equals that of the curve $C = o$, is 29.

9. We have seen that the tangent cone to the surface from a generic point is of class twelve, order sixteen and genus nine (Arts. 6 and 7). It follows from Plucker's formulas (Cf. Salmon, Higher Plane Curves, Chap. 2) that the double developable of the surface is of class twenty-two. The sections of the surface by the planes of this developable are composite, since they have twenty-two double points. The developable itself degenerates into (a) the pencil of planes through the line g, (b) the developable of class six and genus zero (Art. 12) of the planes of the conics on the surface and (c) a developable of class fifteen of planes which intersect the surface in a nodal

*Cf. Caporali in the Collectanea Mathematica in Memoriam D. Chelini, 1881.

cubic and a rational quintic curve. Five plane cubics on the surface pass through a given point on the surface since if, in the λ-plane, we subject a cubic which degenerates into a conic through P and a right line through a given point Q in the plane to the five conditions of belonging to the linear system (3) we obtain five solutions. The curve of class five enveloped by the lines which correspond to nodal cubics cannot have a double or inflectional tangent and is thus of genus six. This is also the genus of the developable of the planes of the cubics on the surface. Each plane cubic has a node which lies on the double curve of the surface. We shall show conversely (Art. 11) that each point of the double curve is the node of a unique plane cubic on the surface. It follows that the double curve is also of genus six.

10. The section of the surface by a triple tangent plane has twenty-three double points and breaks up into three rational curves. There are twenty such planes. Fifteen of them correspond to cubics in (3) which break up into three right lines of which just one passes through P. These fifteen planes are double planes of the developable (c) and simple planes of (b) of Art. 9. Each intersects the surface in two cubics and a conic. Five other planes correspond to cubics in (3) which break up into a conic and a right line, both passing through P. These planes are simple planes on the developables (a), (b) and (c). Each intersects the surface in a rational quintic, a conic and the line g.

11. Since a generic plane section of the surface is of genus one, the nodal curve is of order twenty and forms the complete intersection of the given surface with an adjoint surface of order five. Hence, every curve of order n on the surface intersects the nodal curve in 5 n points. In particular the line g intersects the double curve in five points and the conics on the surface intersect it in ten points from which it follows that the curve C′ in the λ-plane which corresponds to the double curve has a five-fold point at P and is of order fifteen.

Every curve of (3) which passes through a given point Q_1 of C′ also passes through a second point Q_2 of C′ and conversely. To the right line l joining Q_1 and Q_2 corresponds a cubic curve on the surface (Art. 4). This cubic is nodal since every plane which contains the point on it corresponding to

Q_1 also contains the point corresponding to Q_2. Conversely every nodal cubic on the surface corresponds to a right line joining two corresponding points of C'. We conclude that there is a unique cubic on the surface which has a node at a given point of the double curve, that the double curve is of genus six (Art. 9) and that the locus of the lines joining corresponding points of C^1 coincides with the locus corresponding to plane cubic curves.

The points at which Q_1 and Q_2 coincide correspond to pinch-points. There are twenty such points (Art. 7). Each pinch-point is a cusp on a plane cubic on the surface.

Since the arithmetic genus of the surface is zero, the nodal curve has twenty triple points which are also triple points on the surface. The corresponding twenty trios of points in the λ-plane are double points on C' which is thus of genus twenty-one.

12. The equation of the conic on the surface defined by the equation $\lambda_1 = k\,\lambda_2$ (Art. 4) is found by substituting this value of λ_1 into (1) and eliminating λ_2 and λ_3. The result is

$$\begin{vmatrix} x_1 & a^{(1)}_{133}k+a^{1}_{233} & a^{(1)}_{113}k^2+a^{(1)}_{123}k+a^{(1)}_{223} & a^{(1)}_{111}k^3+a^{(1)}_{112}k^2+a^{(1)}_{122}k+a^{(1)}_{222} \\ x_2 & a^{(2)}_{133}k+a^{(2)}_{233} & a^{(2)}_{113}k^2+a^{(2)}_{123}k+a^{(2)}_{223} & a^{(2)}_{111}k^3+a^{(2)}_{112}k^2+a^{(2)}_{122}k+a^{(2)}_{222} \\ x_3 & a^{(3)}_{133}k+a^{(3)}_{233} & a^{(3)}_{113}k^2+a^{(3)}_{123}k+a^{(3)}_{223} & a^{(3)}_{111}k^3+a^{(3)}_{112}k^2+a^{(3)}_{122}k+a^{(3)}_{222} \\ x_4 & a^{(4)}_{133}k+a^{(4)}_{233} & a^{(4)}_{113}k^2+a^{(4)}_{123}k+a^{(4)}_{223} & a^{(4)}_{111}k^3+a^{(4)}_{112}k^2+a^{(4)}_{122}k+a^{(4)}_{222} \end{vmatrix} = 0 \quad (6)$$

As the line $\lambda_1 = k\,\lambda_2$ describes the pencil with vertex at (0,0,1), it is seen from the above equation that the planes of the corresponding conics generate a developable of class six. Five planes of this developable contain the line g (Art. 10).

13. Let the equation of the system of planes (6) be written in the form

$$L_0 k^6 + L_1 k^5 + L_2 k^4 + L_3 k^3 + L_4 k^2 + L_5 k + L_6 = 0 \quad (7)$$

wherein $Li = 0$ $(i = 0, 1, \ldots 6)$ is the equation of a plane. The conic on the surface in the plane $k = \text{const.}$ is the curve of intersection of this plane with the quadric defined by the same value of k of a system of quadrics

$$Q_0 k^5 + Q_1 k^4 + Q_2 k^3 + Q_3 k^2 + Q_4 k + Q_5 = 0 \quad (8)$$

wherein $Q_i = 0$ is the equation of a quadric.*

*Cf. the author, American Journal of Mathematics, Vol. 30, pg. 103.

Since the given surface is of order eight, nine quadrics of this system have the corresponding planes (7) as components. It is no restriction to suppose that these nine quadrics are consecutive at for k infinite. For, if the plane k = a is a component of the corresponding quadric, then

$$Q_0 a^5+Q_1 a^4+Q_2 a^3+Q_3 a^2+Q_4 a+Q_5 = L'(L_0 a^4+L_1 a^3+L_2 a^2+L_3 a^3+L_4 a^2+L_5 a+L_6)$$

Hence k − a is a factor of the left member of the identity

$$L'(L_0 k^6+L_1 k^5+L_2 k^4+L_3 k^3+L_4 k^2+L_5 k+L_6)-(Q_0 k^5+Q_1 k^4+Q_2 k^3+Q_3 k^2+Q_4 k+Q_5)=0.$$

If we remove the factor k − a, we determine the equation of a system of quadrics which is intersected by the planes (7) in the given system of conics and such that L_0 is a component of the corresponding quadric. If we replace the system (8) by this new system and repeat the above operation successively, we determine a system of quadrics whose equation can be written in the form

$$\begin{aligned}&L_0 L'_8 k^5+(L_1 L'_8+L_0 L'_7)k^4+(L_2 L'_8+L_1 L'_7+L_0 L'_6)k^3+\\&(L_3 L'_8+L_2 L'_7+L_1 L'_6+L_0 L'_5)k^2\\&+(L_4 L'_8+L_3 L'_7+L_2 L'_6+L_1 L'_5+L_0 L'_4)k+(L_5 L'_8+\\&L_4 L'_7+L_3 L'_6+L_2 L'_5+L_1 L'_4+L_0 L'_3)=0,\end{aligned}\qquad(9)$$

wherein the linear functions $L'_8, L'_7, \ldots$ satisfy the identities

$$\begin{aligned}&L_6 L'_8+L_5 L'_7+L_4 L'_6+L_3 L'_5+L_2 L'_4+L_1 L'_3+L_0 L'_2=0\\&L_6 L'_7+L_5 L'_6+L_4 L'_5+L_3 L'_4+L_2 L'_3+L_1 L'_2+L_0 L'_1=0\\&L_6 L'_6+L_5 L'_5+L_4 L'_4+L_3 L'_3+L_2 L'_2+L_1 L'_1+L_0 L'_0=0.\end{aligned}\qquad(10)$$

From (7), (9) and the identities (10) it follows that the system of conics on the surface is also determined as the intersection of (7) with any one of the systems of quadrics

$$\begin{aligned}&L_0 L'_6 k^6+(L_1 L'_6+L_0 L'_5)k^4+(L_2 L'_6+L_1 L'_5+L_0 L'_4)k^3+\\&(L_3 L'_6+L_2 L'_5+L_1 L'_4+L_0 L'_3)k^2-(L_6 L'_8+L_5 L'_7)k-L_6 L'_7=0\\&L_0 L'_5 k^6+(L_1 L'_5+L_0 L'_4)k^4+(L_2 L'_5+L_1 L'_4+L_0 L'_3)k^3-\\&(L_6 L'_4+L_5 L'_7+L_4 L'_6)k^2-(L_5 L'_7+L_5 L'_6)k-L_6 L'_6=0\\&L_0 L'_4 k^6+(L_1 L'_4+L_0 L'_3)k^4+(L_2 L'_4+L_1 L'_3+L_0 L'_2)k^3-\\&(L_6 L'_7+L_5 L'_6+L_4 L'_5)k^2-(L_6 L'_6+L_5 L'_5)k-L_6 L'_5=0\\&L_0 L'_3 k^6+(L_1 L'_3+L_0 L'_2)k^4+(L_2 L'_3+L_1 L'_2+L_0 L'_1)k^3-\\&(L_6 L'_6+L_5 L'_5+L_4 L'_4)k^2-(L_6 L'_5+L_5 L'_4)k-L_6 L'_4=0\\&L_0 L'_2 k^6+(L_1 L'_2+L_0 L'_1)k^4-(L_6 L'_6+L_5 L'_5+L_1 L'_4)k^3-\\&(L_6 L'_5+L_5 L'_4+L_4 L'_3)k^2-(L_6 L'_4+L_5 L'_3)k-L_6 L'_3=0\\&L_0 L'_1 k^6+(L_1 L'_1+L_0 L'_0)k^4-(L_6 L'_5+L_5 L'_4+L_4 L'_3)k^3-\\&(L_6 L'_4+L_5 L'_3+L_4 L'_2)k^2-(L_6 L'_3+L_5 L'_2)k-L_6 L'_2=0.\end{aligned}\qquad(11)$$

If we eliminate k between equations (11) and remove the extraneous factor L^2_6, we obtain as the equation of the given surface

$$
\begin{array}{llllllll}
L'_8L'_7L'_6L'_5 & L_2L'_6+L'L'_5+L_0L'_4 & & -(L_3L'_6+L_2L'_5+L_1L'_4+L_0L'_3) & & & & (12)\\
L'_7L'_6L'_5L'_4 & L_2L'_5+L'L'_4+L_0L'_3 & & L_1L'_6+L_3L'_7+L_0L'_5 & & & & \\
L'_6L'_5L'_4L'_3 & L_2L'_4+L'L'_3+L_0L'_2 & & L_1L'_5+L_0L'_6+L_0L'_7 & & & =0 & \\
L'_5L'_4L'_3L'_2 & L_2L'_3+L'L'_2+L_0L'_1 & & L_1L'_4+L_0L'_5+L_0L'_8 & & & & \\
L'_4L'_3L'_2L'_1 & L_2L'_2+L'L'_1+L_0L'_0 & & L_1L'_3+L_0L'_4+L_0L'_5 & & & & \\
L'_3L'_2L'_1L'_0 & -(L_1L'_2+L_1L'_3+L_0L'_4+L_0L'_5) & & L_1L'_2+L_0L'_3+L_0L'_4 & & & &
\end{array}
$$

For points on the double curve, equations (11) have two solutions in common. Hence the surfaces determined by putting the first minors of the left member of (12) equal to zero are adjoints to the given surface. The unique adjoint of order five (Art. 11) is determined from the minor of the last term in the last row as the locus of the equation

$$\begin{vmatrix} L'_3 & L'_7 & L'_6 & L'_5 & L'_4 \\ L'_7 & L'_6 & L'_5 & L'_4 & L'_3 \\ L'_6 & L'_5 & L'_4 & L'_3 & L'_2 \\ L'_5 & L'_4 & L'_3 & L'_2 & L'_1 \\ L'_4 & L'_3 & L'_2 & L'_1 & L'_0 \end{vmatrix} = 0 \qquad (13)$$

At the triple points, similarly, all the second minors of (12) are zero. These points are double points of (13) and make all its first minors zero.

14. The complete linear system of cubic curves to which the system (3) belongs is of eight dimensions. Hence, *the given surface is the projection of a surface of the same order belonging to a space of eight dimensions.* The parametric equations of a surface in eight dimensions of which (1) is a projection can, by a suitable choice of co-ordinate system, be reduced to the form

$$\begin{aligned} &x_1=\lambda^3_1\, x_2=\lambda^2_1\lambda_2\, x_3=\lambda_1\lambda^2_2\, x_4=\lambda^3_2\, x_5=\lambda^2_1\lambda_3\, x_6=\lambda_1\lambda_2\lambda_3 \\ &x_7=\lambda^2_2\lambda_3\;\; x_8=\lambda_1\lambda^2_3\;\; x_9\lambda=_2\lambda^2_3 \end{aligned} \qquad (14)$$

15. If an hyperquadric contains five cubics on the surface (14) it contains the surface, since it has five points in common with each conic on it. Since any two cubics on the surface (14) have a point in common, the hyperquadric contains the surface if it contains $7+6+5+4+3=25$ suitably chosen points on the surface. Since the equation of an hyperquadric in eight dimensions contains forty-five homogeneous constants, *there are twenty linearly independent hyperquadrics which contain the surface.*

The planes of the conics on the surface (14) generate a sextic three-spread V_3^6. The residual intersection of V_3^6 with an hyperquadric which contains the surface (14) degenerates into four planes, since any plane of V_3^6 which has a point not lying on the surface in common with such an hyperquadric lies on the hyperquadric. There are fifteen linearly independent hyperquadrics which contain V_3^6, since an hyperquandric which contains the surface and one point in each of five planes of V_3^6 contains these planes and hence contains the three-spread.

16. *The five-spread generated by the bisecant lines of the surface is of order ten.* For, its section by a four space which contains five generic on the surface clearly contains the lines joining these points. There is no residual intersection, since the projection of the surface from this four-space is a cubic surface with no multiple points. Denote this five-spread by V_5^{10}. The given surface is a four-fold locus on V_5^{10}, since the section of V_5^{10} by the above four-space has a four-fold point at each intersection with the surface.

The five-spread V_5^{10} is generated by the double infinity of three-spaces determined by the cubics on the surface. For, the line of V_5^{10} which joins two given points Q_1 and Q_2 of the surface is a bisecant of the cubic defined by these points and lies in the three-space of the cubic. Conversely, every point in such a three-space lies on a bisecant of the cubic and hence of the surface.

Any two three-spaces of V_5^{10} have a point in common at the intersection of the cubics lying in them. No two have a line in common. Otherwise, they would lie in a five-space and, since each conic on the surface intersects each cubic, an hyperplane which contains the five-space and a point on each of two conics would contain the conics and the cubics and would thus contain the surface.

The surface has no trisecant lines. Otherwise, its projection from such a line would be a non-ruled quintic surface belonging to six dimensions. Similarly it has no quadrisecant planes nor quinquesecant three-spaces.

17. *A generic point of the eight dimensional space defined by the given surface lies on a unique trisecant plane* to the surface. That at least one trisecant plane passes through each point of the space defined by the surface (14) follows from a theorem by Palatini.* Let, then, Q′ be generic point of the given space and Q_1, Q_2, Q_3 be the points of intersection of a trisecant through Q′. Through Q_1, Q_2, Q_3 and a given point R on the right line on the surface there passes a unique quintic curve on the surface (Cf. Art. 4). The given trisecant plane lies in the five-space defined by this quintic curve since Q_1, Q_2, Q_3 lie in the five-space. No other trisecant plane to this quintic curve passes through Q′. Otherwise, the quintic would lie in a four-space defined by the two trisecant planes.

*Atti di Torino, Vol. 41 (1906).

The required number of trisecant planes is, then, the number of quintic curves through R which lie in a five-space through Q'. Let R be chosen so that the quintics through Q' are defined by the conics in the λ-plane whose equations are of the form $\lambda_1 \lambda_2 = a\lambda^2_1 + b\lambda_1\lambda_2 + c\lambda^2_2$. The equations of the quintic corresponding to such a conic are, from (14),

$x_1 = \lambda^5_1 x_2 = \lambda^4_1\lambda_2\, x_3 = \lambda^3_1\lambda^2_2\, x_4 = \lambda^2_1\lambda^3_2\, x_5 = \lambda^3_1\sigma - (\lambda_1\lambda_2)$
$x_6 = \lambda^2_1\lambda_2\sigma\ (\lambda_1\lambda_2)\ x_7 = \lambda_1\lambda^2_2\sigma(\lambda_1\lambda_2)\ x_8 = \lambda_1\sigma^2\ x_9 = \lambda_2\sigma^2$

wherein $\sigma(\lambda_1\lambda_2) = a\lambda_1^2 + b\lambda_1\lambda_2 + c\lambda^2_2$. The condition that the point $Q' = (y_1, y_2, \ldots y_9)$ lies in the five-space of this quintic is that there exists six numbers $l_1, l_2, \ldots, l_6$ such that

$y_1 = l_1\ y_2 = l_2\ y_3 = l_3\ y_4 = l_4\ y_5 = a\,l_1 + b\,l_2 + c\,l_3\ y_6 = a\,l_2 + b\,l_3 + c\,l_4$
$y_7 = a\,l_3 + b\,l_4 + c\,l_5\ y_8 = a^2\,l_1 + 2ab\,l_2 + (b^2 + 2ac)\,l_3 + 2bc\,l_4 + c^2\,l_5$
$y_9 = a^2\,l_2 + 2ab\,l_3 + (b^2 + 2ac)\,l_4 + 2bc\,l_5 + c^2\,l_6.$

If we substitute from the first four of these equations into the next three, we obtain

$ay_1 + by_2 + cy_3 = y_5\quad ay_2 + by_3 + cy_4 = y_6\quad ay_3 + by_4 + c\,l_5 = y_7$

On substituting from these equations into the eighth equation, we obtain

$$ay_5 + by_6 + cy_7 = y_8.$$

These equations determine a unique set of values of a, b and c, and hence a unique quintic curve on the surface whose five-space passes through Q'.

18. The remainder of this paper is devoted to a classification of the surfaces (1) for which the multiple curve has a component of multiplicity not less than three on the surface. To effect this classification, we must first consider the nodal and cuspidal double right lines which may exist on the surface.

19. If the surface (1) has a nodal double right line, a pencil of cubics of the system (3) must degenerate into a fixed right line through P and a pencil of conics. Such a surface is the projection of (14) from a four-space which intersects the plane of a conic on that surface. The nodal line is thus a degenerate conic on the surface (1). If $k = a$ is the parameter of such a degenerate conic, then $k - a$ is a factor of the left member of (6) so that the class of the developable of the planes of the conics is reduced by unity for each nodal line. Conversely, if the class of the developable of the planes of the conics is $6 - q$, then the surface has q nodal lines. Since $6 - q$ is not less than unity, the surface cannot have more than five nodal lines.

The surface has four triple points on each nodal line. These points correspond to the basis points of the pencil of conics corresponding to the residual intersections of the planes through the nodal line. Two pinch-points (Art. 7) lie on each nodal line.

20. If the surface has a cuspidal double right line, all the cubics of the system (3) that belong to certain a pencil degenerate into three right lines through P. Such a surface is the projection of (14) from a four-space which has a plane in common with the four-space which contains the tangent planes to the surface (14) along the right line on the surface. Each tangent plane intersects the four-space of projection in a point.

The residual intersection of a plane through the cuspidal line degenerates into three conics. Each conic touches the cuspidal line at a point and, conversely, each point of the line is the point of tangency of one conic. Six pairs of coplanar conics are consecutive. Since the developable of the planes of the conics is a pencil counted thrice, the surface has also three nodal double lines (Art. 19).

21. If the surface contains a six-fold right line, the residual sections by the planes through this line constitute the pencil of conics on the surface. Since the developable of the planes of these conics is of class one, the surface has five nodal lines which form, with the six-fold line, the complete multiple curve on the surface. One, or at most, two, of the five nodal lines may coincide with the six-fold line. In the former case the six-fold line is formed by the superposition of a triple line, the simple line g and the nodal line. In the latter case, it is formed by the superposition of two nodal lines and a cuspidal line.

22. If the surface contains a five-fold right line, it has a six-fold point on the five-fold line. The residual double curve of order ten has a five-fold point at the six-fold point of the surface and intersects the five-fold line in four other points. The adjoint quintic surface (Art. 11) is the cone projecting this double curve from the six-fold point. One conic on the surface is coplanar with the five-fold line.

If the residual double curve on this surface has a triple component, this component is composed of right lines intersecting the five-fold line. Otherwise, a generic plane section through the five-fold line would be composed entirely of right lines. The double curve may degenerate into a triple line through the six-fold point and a double curve of order seven,

which has a triple point at the six-fold point and intersects the triple line in one and the five-fold line in three other points. It may also degenerate into two triple lines through the six-fold point and a quartic which touches the plane of the plane of the triple lines at the six-fold point and intersects each triple line in one and the five-fold line in two other points.

23. Since the surface cannot contain a non-multiple curve of order four (Art. 4), the residual sections of the surface (1) by the planes through a four-fold line on it degenerate into pairs of conics. The corresponding pencil of cubics of the system (3) consists of a fixed line l and a pencil of pairs of lines through P. If the line l does not pass through P, the four-fold line is formed by the superposition of a triple line and the simple line g; if l passes through P, it is formed by the superposition of a nodal and a cuspidal line. In either case, since the developable of the planes of the conics is a pencil counted twice, there are four nodal lines on the surface.

The residual double curve cannot have a component of multiplicity higher than two. For, such a component must clearly be composed of right lines intersecting the four-fold line, since, otherwise, a generic conic on the surface would be composite. But the surface cannot contain a second four-fold line since it contains only one pencil of conics. Neither can it contain a three-fold line since no conic of the pencil is composite.

24. On a surface (1) which contains a three-fold line there are three four-fold points which lie on the triple line and correspond to the basis points, other than P, of the pencil of conics in the λ-plane, which correspond to the residual intersections of the planes through the triple line. The residual double curve is of genus five. It has a triple point at each four-fold point, intersects the triple line in two other points, and has ten other triple points. Three conics on the surface are coplanar with the triple line.

In case the surface has two triple lines, these lines intersect at a point which is five-fold on the surface. The double curve is of genus four. It has a four-fold point at the five-fold point of the surface, a triple point and two simple points on each triple line and has four other triple points.

When the surface has three triple lines, these lines intersect at a six-fold point of the surface. The double curve is of genus three, has a six-fold point at the six-fold point of the surface and intersects each triple line in two other points. The adjoint quintic is the cone projecting this curve from the six-fold point.

The surface may have four triple lines. These concur at a point which is six-fold on the surface and triple on the residual double curve. The surface cannot have more than four triple lines. Otherwise, it would contain, in the four planes defined by any one triple line and each of the others, four conics coplanar with a given triple line, which is impossible.

25. The multiplicity of a non-rectilinear multiple curve on a surface (1) cannot exceed four. Otherwise, the line joining any two points on the curve would lie on the surface. Neither can the multiplicity of such a curve equal four. If such a four-fold curve were a space curve it would have an apparent double point. Then through a generic point on the surface we could draw a line which would have nine points in common with the surface and would lie on it. If the four-fold curve were a conic C, then through a generic point of the surface there would pass five plane cubics on the surface having their nodes on C. Hence (Cf. Art. 9), the residual multiple curve would degenerate into two double lines and two triple lines which intersect at a five-fold point Q. Then the cone with Q as vertex and C as directrix, would be a component of the surface.

26. Suppose, now, that the surface has a triple curve which does not degenerate entirely into right lines. Through a generic point of this curve no trisecant to the curve can be drawn, since such a line would have nine points in common with the surface and would lie on it. It follows that the surface cannot have a triple curve of order greater than four. For, if the curve were a proper or composite sextic, it would have a four-fold point and lie on a quadric cone which would have an intersection of order eighteen with the surface. Similarly, if it were a proper or composite quintic, this quintic would lie on a quadric cone having the simple line g for its residual intersection with the surface. Then to the triple quintic there would correspond, in the λ-plane, a sextic C having a triple point at P. But the locus of lines joining points of C which correspond to the same point of the surface would then be of order six (at least), which is impossible (Art. 9).

27. If the surface contains a triple quartic, this quartic cannot have infinitely many trisecants and is thus the basis

curve of a pencil of quadrics. The residual intersections of the quadrics of this pencil degenerate into pairs of conics, since the surface is not ruled and does not contain a proper quartic (Art. 4). The surface is thus determined by a (2, 1) correspondence between the quadrics of this pencil and the system of planes of the conics on the surface.

If the triple quartic is not composite, then no quadric of the pencil defined by it can degenerate into two planes of which at least one coincides with a corresponding plane of the developable of the planes of the conics (Cf. Art. 13). There are, then, three conics which degenerate into nodal lines (Art. 19). To the triple quartic corresponds, in the λ-plane, a quartic C which does not pass through P. To each nodal line corresponds a line through P which, since the nodal line cannot intersect the triple curve thrice, is a double line of the locus of lines joining points of C which correspond to the same point on the surface. Hence, the locus of these lines is of class six, which is impossible. There exists, then, no such proper triple quartic. It is seen in a similar way that the surface cannot have a triple cubic and a triple line.

If the triple quartic has a conic as a component, it will be shown (Art. 29) that the developable of the planes of the conics is of class four. There are thus two nodal lines. Since the quadrics of the pencil defined by the triple curve contain two simple conics, the surface is the locus of the conic of intersection of corresponding surfaces of the systems
$L_1 k^4+L_2 k^3+L_3 k^2+L_4 k+L_5=0$ $L_1 L_5 k^2+Qk+L_1 L_5=0$
The triple conics are defined by $L_1=Q=0$ and $L_5=Q=0$. The surface has two nodal lines provided

$$Q=L^2_3+L_1 L_4+L_2 L_5$$

The triple conic $L_5=Q=0$ degenerates into two triple lines in case the four planes $L_1=0$, $L_3=0$, $L_4=0$, $L_5=0$, have a point in common.

28. When the surface contains a triple cubic curve, the curve C in the λ-plane corresponding to this cubic is of order three and does not pass through P. Each conic on the surface passes through the three intersections of the cubic with its plane, since the corresponding line in the λ-plane meets C in three points. It follows that the developable of the planes of

the conics is of class three, since, if P is a point of the triple cubic, every conic whose plane passes through P passes itself through P. There are thus three nodal lines on the surface. Each nodal line intersects the triple curve in two points of which one is four-fold on the surface. The residual double octic is rational. It has a node at a point on each nodal line which is triple on the surface, a node at each four-fold point and intersects the triple curve in six other points. This surface is the projection of the surface (14) from a four-space which is three-fold on a cubic six-spread which contains a curve of order nine lying on the surface (14).

29. If the surface contains a triple conic, the curve in the λ-plane corresponding to this conic is a conic C which does not pass through P. The lines in the λ-plane joining points of C which correspond to the same point of the triple conic envelope a conic, since, through each point of C, there are just two such lines. Two of these lines pass through P and correspond to conics which degenerate into double lines.

In the six-space defined by a generic sextic curve on the surface (14) there are infinitely many hyperquadrics which have a double three-space and contain the sextic curve. The projection of the surface (14) from such a three-space is an octic surface F^8, which belongs to a space of four dimensions and contains a triple conic and two nodal lines. Through a generic point of F^8 there pass two nodal cubics on the surface, the node lying on the triple conic.

The projection of F^8 from a generic point of its space is an octic surface having a triple conic, two double lines and a double curve of order twelve, which has two triple points on the triple conic which are four-fold points on the surface and three double points on each nodal line, which are triple points on the surface.

The projection of F^8 from a point in the plane of a cubic lying on it is an octic surface having a triple conic, a triple and two double lines and a double curve of order nine, which has a triple point at a four-fold point on the triple conic, a node at the intersection of the triple line with each double line and an additional node on each double line.

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" 26. The Supernatural in Hawthorne and Poe.—*Benjamin Mather Woodbridge.*
" 27. "Much Ado About Nothing" and Ben Jonson's "The Case is Altered."—*Homer E. Woodbridge.*
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" 34. European Tales Among the North American Indians.—*Stith Thompson.*

A Study in Variation

By R. J. Gilmore.

The study of variation in the position of the pelvic girdle and asymmetrical attachments in Diemyctylus viridescens was undertaken as introductory to an extended investigation of the girdle in each of the groups of Amphibia. However, the work has progressed so slowly that it seems best to present the following summary of observations thus far obtained.

DIEMYCTYLUS VIRIDESCENS

Diemyctylus is a member of the order Urodela (the salamanders), family Pleurodelidae (the newts). It is commonly known as the newt, evet, or eft. It averages about three to three and a half inches in length. Its color is olive green or shades of red above, lemon yellow below. Each side usually has a row of several rather large scarlet spots, each spot surrounded by a black ring. The belly has small black spots. Diemyctylus occurs in great abundance throughout the eastern United States, north and northeast. The adults live in quiet ponds and lakes. Early in the spring eggs are laid singly and attached to submerged vegetation. The young spend several months in the water as larvae. Late in the summer they transform, leave the water, and live on land in rock crevices, under logs, etc. The color is a bright vermillion, the skin rougher than the adults. In other respects they are entirely similar to the adult. After one or two years on land they return to the water and assume the characteristic color pattern and smooth skin of the adult.

METHODS

In order that the group observed might be representative of the entire population, specimens were taken from widely separated regions and at different times of the year. Formaldehyde was used as a killing and preserving agent. The puboischium and legs were turned aside so that the X-ray photograph might show the true relation of the ilia to the vertebral column. The great value of the X ray lies in the fact that large numbers of specimens may be examined in a short time and that the specimen is not injured for dissection.

THE PELVIC GIRDLE

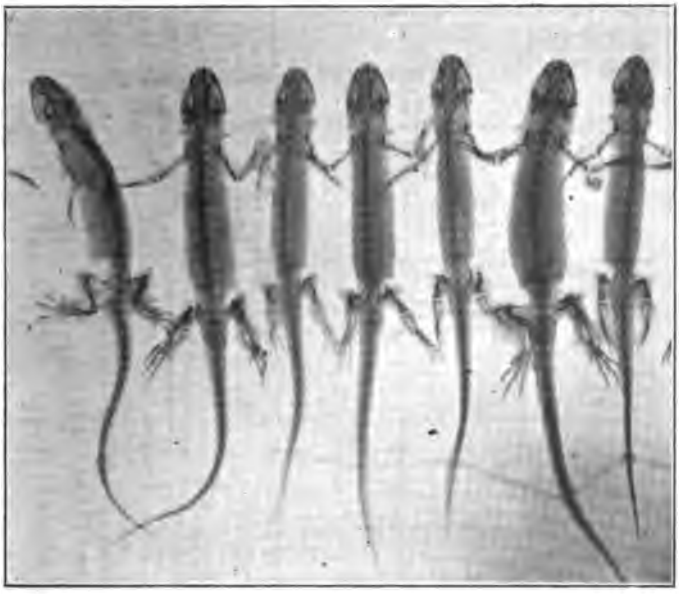
The pelvic girdle consists of a flat ventral plate, the puboischium, the anterior or pubic portion of which extends forward as a slender stalked Y shaped cartilage, the epipubis. Two lateral pieces, the ilia, attach the puboischium to the transverse processes of the sacral vertebra. The ilia stand vertically to the vertebral axis, the distal end slanting slightly forward. They do not meet the transverse processes of the sacral vertebra to form a definite joint but are attached to the anterior surfaces by firm connective tissues. In a normal girdle the two ilia are attached to the transverse processes of the same vertebra. In an asymmetrical or "skew" girdle one ilium is attached to one vertebra and the other to another.

OBSERVATIONS

In all, 1235 specimens of Diemyctylus were photographed by X ray. Of these 1068 had girdles attached to the fifteenth vertebra; 13 to the fourteenth; 107 to the sixteenth; 9 to the fourteenth on one side and the fifteenth on the other; 38 to the fifteenth and sixteenth. In the following tables "sacral vetebra" refers to the serial

number of the sacral vertebra counting from the head. Asymmetrical sacra are indicated by the serial number of each of the vertebrae to which an ilium is attached.

Sacral Vertebra	Male	Female	Total	% of total
14	4	9	13	1.05
14-15	4	5	9	.72
15	589	479	1068	86.48
15-16	23	15	38	3.48
16	43	64	107	8.66



X-ray Protograph of Diemyctylus viridescens.

TOTAL URODELA EXAMINED

	14	14—15	15	15—16	16	16—17	17	17—18	18	18—19	19	19—20	20	20—21	21	total
Diemyctylus torosus	81	3	16	....	.....	....	....	....	....	....	.....	....	....	....	....	100
D. viridescens	13	9	1068	38	107	....	....	....	....	....	.....	....	....	....	....	1235
Salamandra atra	....	..	.....	....	1	....	....	....	....	....	.....	....	....	....	....	1
Ambystoma punctatum	....	..	.....	....	4	....	2	....	....	....	.....	....	....	....	....	6
Anbystoma jeffersonianum	....	..	.....	....	.....	....	4	....	....	....	.....	....	....	....	....	4
Desmognathus fusca	....	..	.....	....	.....	....	6	....	....	....	.....	....	....	....	....	6
Spelerpes longicauda	....	..	.....	....	.....	....	....	....	3	....	.....	....	....	....	....	3
Plethodon glutinosus	....	..	.....	....	.....	....	....	....	....	....	8	....	....	....	....	8
Spelerpes ruber	....	..	.....	....	.....	....	....	....	....	....	5	....	3	....	....	8
Necturus maculatus	....	..	.....	....	.....	....	....	....	1	6	166	15	47	....	1	236
Cryptobranchus allegheniensis	....	..	.....	....	.....	....	....	....	....	....	.....	....	4	1	1	6
Gyrinophilus porphyriticus	....	..	.....	....	.....	....	....	....	....	....	.....	....	2	....	6	8

ANURA

In Rana and Bufo the normal sacral vertebra seems to to be the ninth.

FOSSIL AMPHIBIANS

Branchiosaurus	27
Amphibamus	26
Archigosaurus	25
Micropeton	21
Hyloplesion	20
Keratepeton	20
Eoserpeton	17

THEORETICAL CONSIDERATIONS

To explain variations in the position of the pelvic girdle four theories have been advanced:

1. The theory that variations in the length of the presacral region are due to a movement of the pelvis along the spinal column and that asymmetrical sacra result from and inequality of movement on the two sides of the body.

Rosenberg, ('76, '99) from a study of human embryos and adult skeletons of monkeys, apes, and man came to the conclusion that both onogenetically and phygenetically there has been a forward movement of the pelvic girdle with relation to the vertebral column. He finds that in man at different stages the sacrum is composed of different morphological components—in the early stages, vertebrae 26-30, and, in the later stage, 25-29. He therefore interprets reduction in the number of presacral vertebrae as a progressive step and increase in the number as atavism.

From studies of Pipa and Xenopus, Ridewood ('97) concludes that "When variation in the number of presacral vertebrae does occur, the explanation is to be sought not in the intercalation or excalation of vertebrae, which as Parker ('98) has pointed out are to be looked upon as very rare occurrences, but rather in the shifting of the ilium forward or backward onto the vertebrae in front of or behind the normal.

Slipping is accepted as an explanation by: Solger ('76), Furbinger ('79), Claus ('76), Credner ('86), Paterson ('89), Baur ('91), Eisler ('92), Bolk ('94), Bumpus ('97), Adolphi ('98), and Dwight ('01).

Bumpus ('97) from studies on Necturus arrives at these conclusions: "Of course the easiest way of disposing of this question is to look upon the variation as atavistic. The "ancestral type" was possessed of a larger number of presacral vertebrae and the mud-puppy of today, by its anatomical variation kindly indicates in approximately thirty-five per cent. of its representatives, the character of its quasi-progenitor.

"But, if thirty-five per cent. of the present individuals tend toward presacral multiplication, that is, tend to assume ancestral characters, we must not deny to these potentially progenitorial individuals, the same tendency to vary that is possessed by their young, that is, thirty-five per cent. of the thirty-five should have an added increase of the presacral region, that thus about twelve specimens should have sacral ribs on the 21st and 22nd vertebrae." (the 19th being normal).

It should be noted that Bumpus drew his conclusions from an examination of 100 specimens and makes no attempt to explain forward migration. He offers an explanation of asymmetrical sacra based on the lateral cur-

vature of the embryo. As a matter of fact, the embryo has assumed the straight position long before the first evidence of the girdle has appeared.

To account for the greater frequency of displacement caudad, Bumpus offers the following: "Since the transverse processes to which the sacral ribs are attached lie nearer the caudal limit of the vertebrae it seems more probable that variations occurring in the course of ontogenetic development will fall on the side of nearer proximity, that is, into the next segment caudad, and having once invaded the territory of this new segment, the ribs will be adjusted to the proper position within that segment."

He accounts for the variation of the position of the sacrum by assuming that its appendage has a locus, fixed at a point whose linear distance from the cranium is a definite and constant proportion of the entire length of the animal. The change in position of the girdle is then affected by compressing the vertebrae, making each shorter and diminishing their combined length, thus bringing a vertebra caudad to the normal, opposite the stationary appendage locus.

THEORY 2

That variations in the length of the presacral region and asymmetrical sacra are the results of the intercalation or excalation of one or more whole or partial vertebrae.

This theory was first advanced by H. V. Ihering ('78) accepted by Albrecht ('83), Bourne ('94), Benham ('94), Adolphi ('96) and others. Baur ('91) claims intercalation as an actual ontogenetic process. He says, "My opinion is that in the increase of the number of seg-

ments not only in vertebrates, but also in invertebrates, intercalation has played a much greater role than is generally admitted. At the same time, I admit addition of segments at the distal end, as well as occasional slight migration of the shoulder girdle and pelvis in both directions."

Parker ('96) says, "Baur has shown very conclusively that, in place of one vertebra, two or parts of two, may arise, the process evidently being a partial division of the material from which a single vertebra ordinarily arises. This process which I should call the multiplication rather than the intercalation of vertebrae may in some cases account for the increase of presacral elements, but I am not inclined to ascribe to it the wide-spread importance that Baur does."

Waite ('97) working on the nerve plexuses of Necturus found "variations in the brachial plexus are independent of variation in the position of the pelvic girdle; and since there is not posterior displacement of the brachial plexus, nor any change of topography in cases where the pelvic girdle is placed on the 20th vertebrae, we have evidence that there has been no interpolation of vertebrae in the part of the column anterior to the posterior limit of the brachial plexus." He therefore concludes that no intercalation has taken place for "since serial variation tends to be at one end of the series, it is more to be expected in the prebrachial region than in the postbrachial-presacral region.

"An actual increase in number of vertebrae, and also an indicated increase by grooving and partial splitting of vertebrae, and by bifurcation of transverse processes, have been noticed by Bourne ('84), Benham ('94), and others. The cases of actual increase described in Anura, are results from separation of the anterior portion of

the urostyle as a supernumerary vertebra. Adolphi ('95) has recorded forty-three cases of fusion in Bufo, Pelobates, and Rana, and has determined the nerve relations. He finds that in such cases of fusion the spinal nerves are not suppressed, but emerge through foramina in the fused mass: they are, however, likely to be weaker than normal.

"Such supposed direct evidence of intercalation and excalation is capable of being interpreted as pathological, rather than as a disturbance tending primarily to alter the serial number of metameres, especially since it is almost entirely confined to the skeleton, without involving musculature or nerves beyond the narrow limits necessitated by local accommodation to the distorted vertebrae."

In 1235 specimens of Diemictylus viridescens, I have found one specimen only which showed any evidence of fusion. In this case the two vertebrae were only partially fused, each maintaining its own identity. Both lateral spines were present.

THEORY 3

Variations in the length of the presacral region are due to an initial variation in the serial number and position of centers of metamerism.

This theory was first advanced by Welcker ('78) and later by Bateson ('95). Regarding it, Winslow ('04) says, "No attempt is made to explain asymmetrical sacra by this theory alone, but it is regarded by its advocates as offering the only admissible explanation for such variations as that between the pigeon's neck with 15 vertebrae and that of the swan with 26 and similar cases in the necks of the Plesiosauria mentioned below." (taken from Baur ('97).

	Cervicals	Dorsals	Sacrals	Total
Pliosaurus evansi	19-20			
Pelonesustes philarchus	20-21			
Plesiosaurus rostratus	28	20	2	50
Plesiosaurus macrocephalus	30	20	2	52
Thaumatosaurus megacephalus	30	26	2	58
Plesiosaurus hawkinsi	31	23	2	56
Cryptoclidus	31	23	2	56
Plesiosaurus guilelmi imperatoris	35	20	2	57
Plesiosaurus conybeari	38	22	2	61
Plesiosaurus homalospondylus	38	22	2	62
Plesiosaurus dolichodeirus	41	21	2	64
Muraenosaurus plicatus	44			
Elasmosaurus platyurus	72	20	2	94

This theory is more acceptable than intercalation or excalation as a morphological process, since it preserves the integrity of the metameres.

Howes and Dwight accept this theory, but Waite objects on the ground that: "It has no observational evidence to support it and further is insufficient to account for unsymmetrical sacra and supernumerary sacral ribs."

Kingsley ('10) suggests an hypothesis based on the ability of worms and allied forms to reproduce asexually by fission and subsequent growth of new parts from the somites directly in front of and behind the point of division. "At least certain somites in the body have the potentialities of forming material for additional somites and must contain within them the same possibilities as the original teloblasts from which they arise. In other words in the annelid, before the beginning of the transverse division, the capacity for producing new tissues was located at more than one point in the body, but it was not exercised until after the asexual reproduction was well advanced.

In the same way the assumption that there are similar budding zones at various points in the vertebrate body will explain certain skeletal variations.

In the vertebrates there is a continuous addition of new somites at the posterior end of the body as in the arthropods and annelids, implying the existence of the equivalent of teloblasts at the posterior end. In the same way we may explain the varying number of vertebrae in the different regions and allow at least one of the pelvic vertebrae to be regarded as a fixed point, and we may be relieved of any assumption of a shifting of the girdles. It will also explain many anomalies such as the attachment of two halves of the pelvis to different vertebrae and the increased number of lumbar or thoracic vertebrae in man. So far as I am aware no one has seen such zones in any vertebrate. In fact it is extremely probable that there is no such well defined zone as is found in the teleblasts of inverterbrates."

THEORY 4

Variations in the number of presacral vertebrae and asymmetrical sacra are due to the fact that the sacral region has the power of developing sacral ribs and pelves at several points on both right and left sides.

This theory was proposed by Parker ('96) and Waite ('97). Waite concludes: "It is more logical to consider that the new position of the girdle is due to a stimulus to girdle formation having been applied to a new point, that is, in a segment other than the normal and hence that a sacral rib may arise in any one of several points in this region. (More than one sacral rib was found in several cases). In Necturus these points are at least three, located in the 18th, 19th, and 20th segments. Since the stimulus to girdle formation is not single but paired, that is, from the future appendages, it need not necessarily be symmetrical. . . . . Neither intercalation or excalation, nor slipping are involved, but the abnormal position represents development of a new girdle in a new place."

Winslow ('04) describes a specimen of Ambystoma punctatum in which three legs and two girdles were found in the pelvic region. The one girdle with its appendages was attached normally; the other had no connection with the spinal column. All the elements of a normal girdle were present. Winslow concludes, "Very little remains to be desired to prove the truth of the proposition that sacral ribs and appendages may arise at any one of several points.

"The idea that there are several points on the side of the body capable of producing an appendage is, in a way, a corollary of the facts discussed by Bateson ('94) under the head of homeosis; for, in saying that a segment may assume the form of the segment in front of or behind it we practically say that the segment has in itself potentially the qualities which are normal to the two adjacent segments."

By the majority of the authors above quoted the pelvic girdle is treated as an entity. Waite, on the other hand, finds that shifting of the girdle is associated with the formation of a new nerve plexus, that is, the introduction of new nerves into the plexus. Goodrich ('09) says, "That, in a series of metameric myotomes and nerves, each motor nerve remains, on the whole, faithful to its myotome throughout all the vicissitudes of phylogenetic and ontogenetic modifications, may be considered as established."

Referring to the migration of paired fins in fishes Lancaster concludes: "Considerable apparent migration is brought about by processes of concentration, growth, and reduction. It has already been mentioned than any trunk segment may contribute to the production of a limb, and we find that the segments of the region occupied by the limb in the adult always share in its development. The limb as a whole, retains its position throughout ontogeny. But if reduction takes place in front, and growth takes place behind or vice versa,—if in other

words, certain segments cease to contribute at one end, and certain segments begin to contribute at the other, then apparent motion takes place backwards or forwards. The nerve supply of the adult limb is a sure guide to the identification of the segments from which the muscles have been derived. Segments before and behind the limb plexus may no longer enter into the formation of the limb owing to reduction: but the adult nerves undoubtedly show which segments contribute most to the musculature. Now, as Furbringer has shown, a limb plexus shifts backwards or forwards like the limb it supplies. Its change of position can be accounted for neither by the theory of inter- or excalation of segments nor by the supposition that the nerves actually move through the segments. It is, therefore, by progressive growth in one direction, and by corresponding reduction in the other, that change of position takes place. The motion is only apparent, and is not due to the actual migration of the ready formed material from one segment to another, but may be said to be due to 'transposition' from one set of segments to another set up or down the series."

SUMMARY

Regarding the first theory, that variations in the presacral region are due to a movement of the pelvis along the spinal column, while unable to offer any proof that this type of variation does not occur, I am alike unable to find any proof that it does occur. The acceptance of this theory would necessitate belief that the girdle is an entity, that is, that the same segments take part in its formation no matter what the position. If this were true, the pelvis would be associated invariably with the same nerves. In other words, if the girdle were formed by segments 15, 16, 17, nerves corresponding to these would be associated with it even though the attachment were on the 14 segment. According to Waite this is not the case in Necturus, and according to Lancaster it is not

the case in fishes, where the pelvic girdle may be found, in some instances, in front of the pectoral.

If the word movement is to be interpreted, not literally but as Lancaster suggests, this theory and that of Waite are identical.

The second theory—excalation and intercalation of vertebrae—has no conclusive evidence for or against it. In most cases pathological conditions offer a more natural conclusion from the data at hand. Waite's argument that this phenomenon is probable, on account of the fact that caudal migration of the pelvic girdle is not associated with migration of the pectoral plexus, does not seem conclusive. For, in the first place, he assumes that when excalation or intercalation takes place it should be at one end of a linear series. He eliminates the possibility of change between the first and last vertebrae. And furthermore the absence of variation in the pectoral region does not prove anything, since he cannot deny the possibility of a "new girdle in a new place" in pectoral region, if we are to accept that theory for the pelvic. I cannot see that there is any way to prove that this phenomenon does not take place, though an explanation on the basis of pathology seems more logical.

In the third theory we assume that there is a variation in early segmentation. In Diemyctylus we would hold that the part of the embryo which normally produces 15 vertebrae, forms 16 or 14 as the case may be. According to the theory of ex- and intercalation, the addition or subtraction of segments is accomplished by the division or fusion of ready formed segments. As a morphological speculation, variation in early segmentation is more acceptable, since it preserves the integrity of metameres. There is no evidence for or against this theory.

The fourth theory, "a new girdle, a new plexus, in a new place" seems most plausible. The arguments in its

favor have been stated above in the words of those who advanced it.

For the present, I am content to consider this the most probable solution and shall direct further work to investigate its soundness.

PROBABLE SIGNIFICANCE OF VARIATION IN THE LENGTH OF THE PRESACRAL REGION IN AMPHIBIA

Whatever may have been the method of girdle migration the fact that the length of the presacral region differs in different groups and varies in any one group suggests the possibility that these facts may have a phylogenetic significance.

A comparison of the three groups in which the largest numbers of specimens were examined seems to indicate that Necturus is less "stable" than Diemyctylus viridecsens or Diemyctylus torosus. Necturus is strictly aquatic; D. viridescens is aquatic as a larva, terrestrial for a time and secondarily aquatic: D. torosus is essentially terrestrial, spending only a brief larval period in the water.

Attachment of pelvic girdle	D. torosus	D. viridescens	Necturus
One vertebra ahead of normal	0%	1.05%	.84%
Skew ahead of normal	0%	.72%	2.53%
Normal	**81%**	**86.48%**	**70.04%**
Skew behind normal	3%	3.48%	6.32%
One vertebra behind normal	16%	8.66%	19.83%
Two vertebrae behind normal	0%	0%	.42%
Total Specimens Examined	100	1235	236

X-Ray Photograph of Cryptobranchus.

This raises the question as to whether the apparent stability of torosus and viridescens is due to the greater necessity for well developed arms and legs.

A comparison of the habits of life of urodela and the girdle attachments presents some striking facts.

There appear to be two extremes of habitat and a medium. The latter is not clearly defined. The first extreme includes forms which live wholly in the water—Cryptobranchus, Necturus, Gyrinophilus. The weight of the body is supported by the water. Locomotion is accomplished by the action of the tail. Arms and legs are used for pushing and pulling the body as the animal moves slowly on the bottom of the pond. The position of arms and legs is of no great importance to the animal as a survival character. The girdle is attached on 18-19-20-21.

The second extreme includes those forms which walk on land. The legs of this group raise the body from the ground and pull or push it forward. This type of locomotion requires that the belly and at least the proximal end of the tail, be raised above the ground. This requirement might be met in one of two ways. First, the stiffening of the vertebral column and lengthening of the legs: second, the reduction of the distance between arms and legs. Among larger terrestrial types the former method prevails: among urodela the latter. If the distance between arms and legs is to be reduced, such reduction must result from a forward migration of the pelvic girdle rather than a backward migration of the pectoral. For the arms must support the head and therefore are limited as to their migration. In this group are included Diemyctylus, Salamandra, Ambystoma, Desmognathus, whose attachments range from 14, 15, 16, 17.

The group of urodeles which occupies the median position shades off gradually into the two extreme groups. These forms raise the body very slightly when moving on land. Locomotion is a combination of wriggling, pushing, and pulling.

The anura jump. The presacral region is reduced to nine vertebrae and in some species is as low as five.

Can mechanical stress and strain be responsible for the differences in the different groups? Walking is the resultant of several forces. There is first the downward push of the body which is counteracted by the upward push of arms and legs. A second force is the forward pull of arms and legs. This force is applied on the points of attachment of the ilia and the muscles of the side of the body.

Cope ('95) argues: "The constant strain of use will produce variation in one line, or constant use along a straight line will be the factor of natural selection which would cause the elimination of all variations, except those in the line defined by environment. Transformations whether in the way of addition of new parts or the reduction of those already present act just as if the direct action of the environment and the habits of the animal were the causes of the changes, and any explanation which excludes the direct action of such agencies is confronted by the difficulty of an immense number of most striking coincidents. The theory of determinate variations and use inheritance is not antagonistic but supplementary to natural selection, the latter theory attempting no explanation of the cause of variation. Nor is it pretended for a moment that use and disuse are the sole factors or even the chief factors."

Variations in other characters was observed in an effort to determine whether animals which showed pelvic variations were more variable in other respects. The number of vermillion spots were counted and the specimens were measured as to length. These results were subjected to the mathematical formulas designed for the purpose and showed results which could not be regarded as conclusive. A much larger number of specimens will be necessary before observations of this sort can be considered significant.

CONCLUSION

The data herein included are far too meager to justify a trustworthy conclusion. If they point the way for further study they have done well.

PROBLEMS SUGGESTED

1. A close study of the environment of amphibia.

2. A close study of the mechanics of locomotion.

3. Correlation of girdle attachment with present basis of classification.

4. The development of the pelvic girdle.

5. Is the shifting of the girdle through one segment a survival character?

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NOTES ON THE LIFE HISTORY AND FEEDING HABITS OF THE SPADEFOOT TOAD OF THE WESTERN PLAINS

—BY—

R. J. GILMORE.

COLORADO SPRINGS, COLORADO

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Notes on the Life History and Feeding Habits of the SPADEFOOT TOAD of the Western Plains

by

R. J. GILMORE

Colorado Springs, Colorado
December, 1924

NOTES ON THE LIFE HISTORY AND FEEDING HABITS OF THE SPADEFOOT TOAD OF THE WESTERN PLAINS

RANGE

The spadefoot toad of the western plains, *Scaphiopus hammondii bombifrons,* Cope, is found in the north part of the western plains of the United States. It is reported from Texas, Arizona, Colorado, Dakota, Montana, and Idaho. It is sparsely distributed over most of its range, but occurs in abundance over very limited areas.

LOCAL HABITAT

East of Colorado Springs in the low rolling hills is one of these areas. The soil is a mixture of sand, gravel, and loam and generally quite dry. It is here that adult spadefoot toads are found at depths varying from a few inches to several feet.

DESCRIPTION

The spadefoot toad is rather small, the total length of body being two inches. The legs are short; the hands are unusually small and the fingers short. The foot is webbed, the webs deeply indented. On the inner sole a black horny sharp-edged tubercle—the "spade"—is developed. This is the principal instrument for burrowing. (Fig. 1)

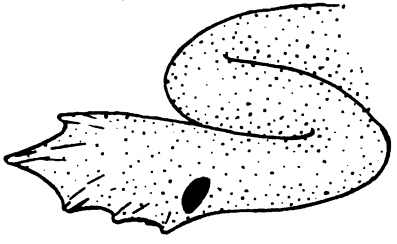

FIGURE I. "Spade" on sole of foot.

The skin is smooth and fine in texture, yellowish olive to dark gray in color. Two curving dark bands extend backward from the eyes. These bands are made of spots, each of which has a smooth orange-colored tubercle at its center. In some specimens the bands are indistinct, the entire back being of uniform color. The underparts are dingy white, purplish posteriorly, the throat blackish. The snout is short;the end rather squarely truncated. The end of the snout is covered

with heavy horny skin, which is continued posteriorly between the eyes to the top of the head. Between the eyes it is thickened to form a marked elevation.

The large eyes face forward and outward. The pupil is vertical, a characteristic found only in spadefoot toads and one other very rare form found in the state of Washington. The iris is golden, the ear not distinct.

The short body, the large eyes, the shortness and thickness of the snout give to the spadefoot a curious pug-dog expression. (Fig. 2)

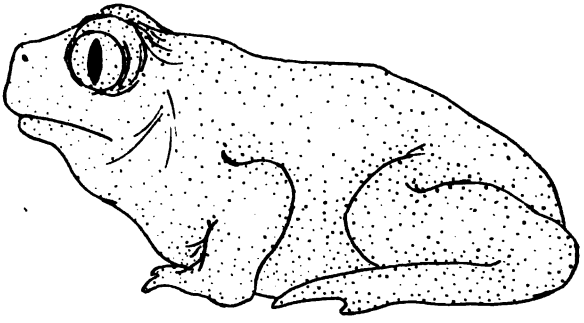

FIGURE II. Adult Spadefoot Toad.

HABITS

The spadefoot lives underground in burrows of its own making, and is seldom seen above ground except during continuous rains. It usually chooses soft ground in which to burrow. With its spade-armed feet it pushes the soil aside, and by a slow rocking movement sinks backwards beneath the surface of the ground. The heavy skin of the head is probably used to keep the burrow open in front or to pack the earth of the walls of the burrow. The descending toad leaves no trace on the surface to indicate its course.

FEEDING HABITS

The feeding habits of the adult spadefoot are not known. It is probable that they are similar to those of the eastern representatives of the genus. These come to the surface at night. The vertical catlike pupil leads one to suspect nocturnal habits. It seems highly improbable that sufficient food could be gathered underground.

BREEDING SEASON

The time of breeding is dependent on heavy rains of early summer. At such times the sandy soil is saturated, and temporary pools are formed in the valleys. To these pools the toads migrate in almost incredible numbers.

SEASONS IN COLORADO SPRINGS

Near Colorado Springs, Colorado, where these observations were made, there is usually a short season of heavy rains early in the summer. This season is preceded and followed by periods of dryness. In 1921 the first appearance of the spadefoot was May 31. On July 5-6 a second rain brought out another group. In 1922 the first appearance was June 1. A very few others appeared later. In 1923, June 15 was the date of first appearance. In 1924, after thirteen days of continuous drizzling rain, the first spadefoot was observed May 31. At nine o'clock in the morning eight male specimens were found. At three o'clock in the afternoon twelve were found. Mating had begun. At nine o'clock in the morning of June 1, mating animals were present in hundreds. A few eggs had been laid. June 2 eggs were abundant and some individuals had started back toward the hills. From the number of egg masses it seems probable that not all mated pairs laid eggs. June 3 only a small group remained in the water.

BREEDING HABITS

After arriving at the ponds the male spadefoot indulges in very vigorous nuptial song, which continues without interruption until the mating has been completed. The effect has been described as "weird plaintive cries," "hoarse and woeful." The individual song somewhat resembles that of *Rana palustris*.

Very soon after reaching the water, mating begins. The males grasp the females just in front of the legs. The process of mating and egg laying occupies from twenty-four to forty-eight hours. If rains continue the adults may remain in the water for several days; but more commonly they leave the pond immediately after the eggs have been laid.

EGG MASS

The egg masses vary in size. (Fig. 3) Large masses contain 200 to 250 eggs, smaller ones 10 to 50. The mass is attached to submerged vegetation, or to any object protruding from the bottom. The mass is elliptical in shape. (Fig. 3)

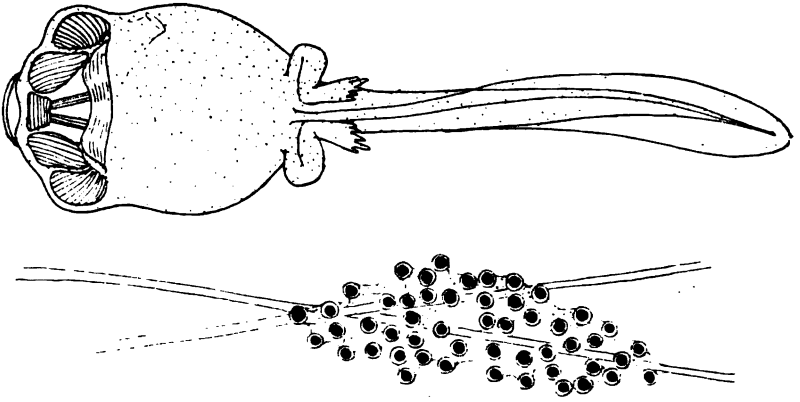

FIGURE III. Egg mass of Spadefoot Toad. Muscles of Spadefoot Tadpole. Ventral view.

INCUBATION PERIOD

The incubation period as observed in the field seems to be less than forty-eight hours. This is probably due to the very warm condition of the water. In 1924, long continued cloudy weather retarded the hatching.

RATE OF GROWTH

The newly hatched tadpole is a trifle less than one-fourth of an inch in length. Within less than five days it has doubled in size. Within another five days it has attained a length of one inch. The legs then begin to develop. Fifteen days later it has reached its maximum size. Two and one-half inches is the maximum length of the majority of adults in any tadpole community. A small minority attains three to three and three-quarters inches in length. At about the thirtieth day after egg-laying, arms begin to appear, and the process of transformation begins to be evident in all parts of the animal. The complete absorption of the tail and the completion of remodeling of all structures into adult form is accomplished by the fortieth day. (Fig. 4)

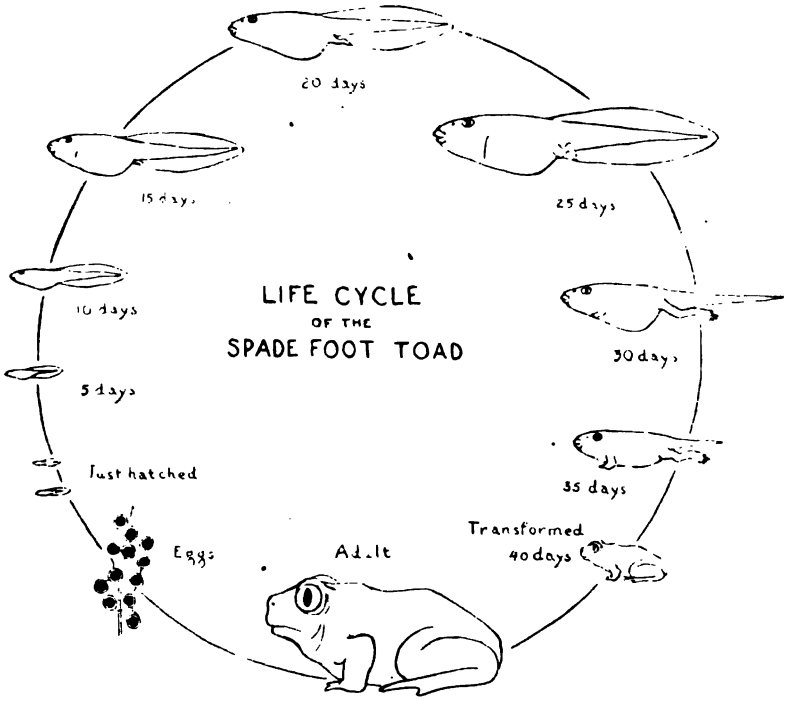

FIGURE 4. Life cycle of Spadefoot Toad based on observations made near Colorado Springs, Colorado.

In 1921, specimens were found to be completely transformed after thirty-six to forty days. In 1923, the shortest observed period was thirty-nine days.

THE HABITAT OF TADPOLES

The spadefoot chooses temporary ponds in which to rear its young. In no cases have eggs or tadpoles been observed in permanent lakes, although such lakes are available. The ponds are roadside mud-holes and low areas in fields ranging from a few inches to a few feet in depth. The water is muddy and warm. The vegetation consists of such microscopic plants as have passed the winter in a resting condition in the dried mud at the bottom. A few plants of Marsilea, some of the coarser grasses, sedges, and rushes may be present. To the

casual observer the ponds seem unusually barren. The animal life is rich and varied. Protozoa are present in abundance. Rotifers are common. Various of the smaller worms are abundant. The larvae of aquatic beetles, bugs and diptera are present in small numbers. The dominant fauna consists of crustaceans. Of the phyllopods several species of shrimp are numerous, (*Streptocephalus, Thamnocephalus, Apus, Estheria*). Of the Cladocera, *Daphnia* and other genera are represented. These attain to unusual size and abundance. Of the Copepods, *Cyclops, Diaptomus* and other genera are abundant.

It is in this environment, poor in larger plants, rich in animal life, that the spadefoot tadpole develops. This may account for the development of the carnivorous habit.

UNEVENESS OF GROWTH

At no time during the season of growth are all tadpoles of even approximately the same size. From ten to twenty per cent. of specimens known to have hatched at the same time are considerably larger than the average. Some may be two to three times the size of the average. These larger forms are frequently found with smaller ones half eaten.

FOOD

The larger tadpoles seem to feed exclusively on living animals. Smaller tadpoles, shrimps, and insect larvae constitute their diet. The feeding habits have not been observed closely enough to make possible a conclusive statement as to whether living animals constitute the entire diet. Whether the smaller specimens feed on small crustaceans or on plant materials has not been determined. The evidence at hand favors strictly carnivorous diet.

ADAPTATIONS TO ANIMAL DIET

The structures about the mouth of the spadefoot tadpole are admirably adapted for a diet of living animals. The horny jaws (Fig. 6) are constructed for seizing and holding prey.

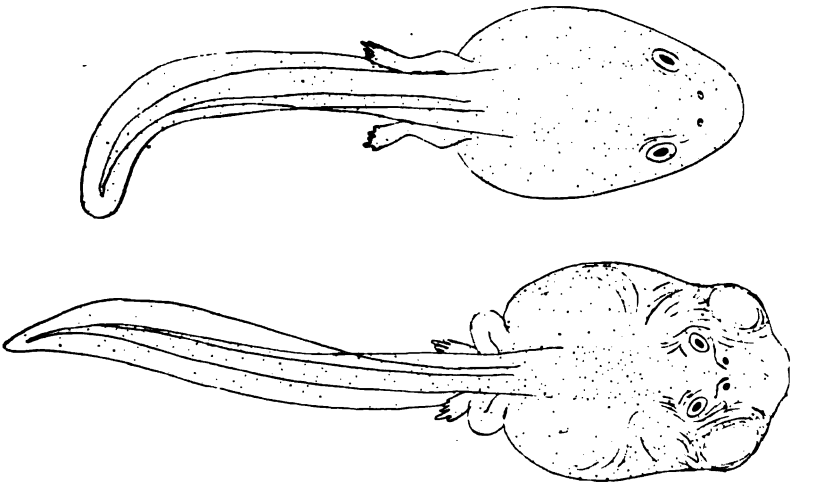

FIGURE V. Dorsal view of Spadefoot Tadpole.—(below). Dorsal view of tadpole of Common Frog.—(above)

They are capable of being opened to accommodate large prey. On the roof of the mouth is a median horny recurved tooth. This is not found in herbivorous tadpoles. The lips (Fig. 7)

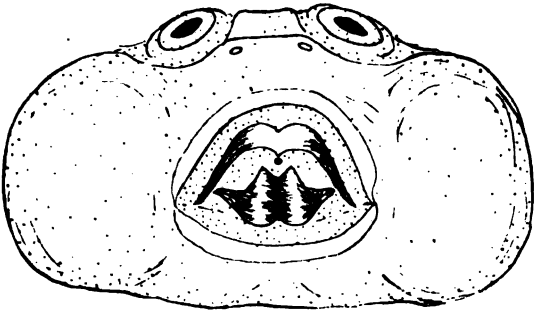

FIGURE VI. Face view of Spadefoot Tadpole, mouth opened, lips turned back.

are flat and thin and probably assist in the capture and holding of prey. Food is not swallowed whole as in the adult toad, but is held in the jaws and sucked or torn to small bits.

The feeding apparatus is operated by an unusual development of mouth muscles. (Fig. 3)

COMPARISON WITH OTHER TADPOLES

In order to show the peculiar development of the spadefoot, drawings were made of the tadpole of the common frog *Rana pipiens*. The shape of the mouth (Fig. 7) shows the dif-

ference between a raptorial equipment and one adapted for sucking or nibbling. The jaw muscles give the spadefoot a distinctive outline. (Fig. 5). Figure 6 shows a face view

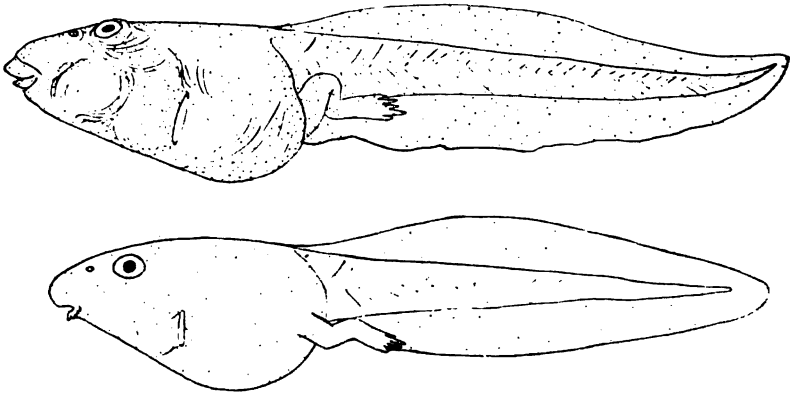

FIGURE VII. Side view of Spadefoot Toad (above). Dorsal view of tadpole of Common Frog (below).

of a spadefoot, the mouth opened and lips turned back. The epidermal structures consist of jaws and one tooth on the roof of the mouth. In *pipiens* a series of rows of small horny tubercles on the inner side of the lips assist in nibbling attached food. Pipiens will eat animal material, but only by nibbling or sucking small pieces from a dead carcass. The majority of toad and frog tadpoles are similar to *pipiens* in structure and habits.

LENGTH OF INTESTINE

The discovery of the peculiar food habit of the spadefoot raised the question as to whether or not the alimentary tract showed modifications adjusting it to a flesh diet. Two groups of animals were selected and measurements made.

Group I is a typical sample from a pond in which all tadpoles were known to be of the same age.

Group II includes large specimens taken at random without regard to age.

In both groups transformation had not proceeded beyond the development of legs. It follows, then, that whatever variation there may be in length of intestine cannot be attributed to transformation.

DISTRIBUTION OF SPECIMENS ACCORDING TO SIZE AND LENGTH OF INTESTINE

GROUP I

Tadpoles taken from Nob Hill June 30, 1923. Age 15 days.

Length of Tadpole from tip of nose to tip of tail.

Length of Intestine	1½″	1¾″	2″	2¼″	2½″	2¾″	3″	3¼″
29 inches	0	0	0	0	0	0	0	0
28 ″	0	0	0	0	0	0	0	0
27 ″	0	0	1	0	0	0	0	0
26 ″	0	1	0	0	0	0	0	0
25 ″	0	1	0	0	0	0	0	0
24 ″	2	2	1	0	0	0	0	0
23 ″	0	4	0	0	0	0	0	0
22 ″	2	6	0	0	0	0	0	0
21 ″	2	4	0	0	0	0	0	0
20 ″	1	8	0	0	0	0	0	0
19 ″	5	3	2	0	0	0	0	0
18 ″	7	8	1	0	0	0	0	0
17 ″	1	6	0	0	0	0	0	0
16 ″	2	3	0	0	0	0	0	0
15 ″	4	0	0	1	0	0	0	0
14 ″	2	3	0	0	0	0	0	0
13 ″	3	1	1	0	0	0	0	0
12 ″	5	0	0	0	0	0	0	0
11 ″	1	0	0	0	0	0	0	0
10 ″	2	2	0	0	0	0	0	0
9 ″	1	0	1	3	0	0	0	0
8 ″	1	0	0	0	0	0	0	0
7 ″	2	0	1	1	0	0	0	0
6 ″	0	0	2	0	0	0	0	0
5 ″	0	0	1	0	1	0	0	0
4 ″	0	2	0	2	2	0	0	0
3 ″	2	1	1	0	1	0	0	0
2 ″	0	0	0	0	0	0	0	0
	45	55	12	7	4	0	0	0

GROUP II.

TADPOLES TAKEN AT RANDOM

Length of Tadpole from tip of nose to tip of tail.

Length of Intestine	1½"	1¾"	2"	2¼"	2½"	2¾"	3"	3¼"	3½"	3¾"
30 inches	1	0	0	0	1	0	1	0	0	0
29 "	0	0	0	0	0	1	0	0	0	0
28 "	0	0	2	0	0	0	0	0	0	0
27 "	0	0	0	0	1	0	0	0	0	0
26 "	0	0	0	1	0	0	0	0	0	0
25 "	0	0	0	0	1	1	0	1	0	0
24 "	0	0	1	1	0	0	0	0	0	1
23 "	0	0	0	1	0	0	0	0	0	0
22 "	0	0	0	0	0	0	0	0	0	0
21 "	0	0	0	0	0	0	0	0	0	0
20 "	0	0	0	1	0	0	1	0	0	0
19 "	0	0	1	0	0	0	0	0	0	0
18 "	0	1	0	1	1	0	0	0	0	0
17 "	0	0	0	0	0	0	0	0	0	0
16 "	0	1	0	0	0	0	0	0	0	0
15 "	0	0	0	1	1	0	1	0	0	0
14 "	0	0	0	0	0	0	0	0	0	0
13 "	0	0	1	0	0	0	0	0	0	0
12 "	0	0	0	0	0	0	0	0	0	0
11 "	0	0	0	0	0	0	0	0	0	0
10 "	0	0	1	0	0	0	0	0	1	0
9 "	0	0	2	0	1	0	0	0	0	0
8 "	0	0	0	1	2	0	2	0	0	0
7 "	0	0	2	2	3	1	0	0	0	0
6 "	0	0	2	3	4	3	0	0	0	0
5 "	0	0	0	2	0	2	0	0	0	0
4 "	0	0	0	0	2	0	0	0	0	0
3 "	0	0	1	0	0	0	0	0	0	0
2 "	1	0	0	0	1	0	0	0	0	0
1 "	0	0	0	0	0	0	0	0	0	0
	2	2	13	14	18	8	5	1	1	1

SUMMARY I

Including all specimens.

Intestine Length	Group I	Group II	Total
20-30 inches	37	17	54
10-20 "	63	11	74
1-10 "	25	36	61

SUMMARY II

Including all specimens two inches long and over.

Intestine Length	Group I	Group II	Total
20-30 inches	2	16	18
10-20 "	5	5	10
1-10 "	16	36	52

The above data are not sufficient to furnish the basis of conclusive computations on variability. They show a peculiarity which falls outside the realm of fluctuating variations. A range in length of intestine from two to thirty inches in animals of the same size and age is too great to pass unnoticed.

In the summaries above the percentage of short animals having short intestines is high. In the summary of specimens two inches long or over the short intestine group outnumbers the total of the long and medium classes.

SIGNIFICANCE OF VARIATIONS

Is there any significance to these variations? The tadpoles of most frogs and toads are herbivorous and therefore have very long intestines. As they transform to the adult condition they take only animal food, and the long intestine is replaced by a short one. In the spadefoot the change from a long to a short intestine seems to take place before the beginning of transformation. In fact, some specimens seem never to have had a long intestine. It seems probable that the spadefoot tadpole is departing from the traditions of its ancestors and relatives and adjusting itself to a new type of diet. This adjustment is approaching perfection in the jaws, lips, roof of the

mouth, and jaw muscles. The long intestine character has not been eliminated, but is in process of elimination. It seems to persist during early tadpole life and is later supplanted by a short intestine. The short intestine character will be subject to a wide range of variability until it has firmly established itself on the race.

The materials included in this study will be investigated further in the hope that some satisfactory conclusions may be reached.

The author wishes to express appreciation for assistance rendered by Russell P. Hunter in collecting material, Thelma Bradley for measurement of specimens and Helen Sewell for illustrations.

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By

G. W. GOLDSMITH
and J. H. C. SMITH

February, 1926

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Some Physico-Chemical Properties of Spruce Sap and Their Seasonal and Altitudinal Variation

Vegetational zones are conspicuous features of mountain regions, which consequently offer an especially favorable field for the ecological study of plant distribution. As was long ago emphasized (Clements 1905), this is primarily a matter of the intimate physiology of the dominant species, under measured or controlled conditions in the actual habitat. This demands that the investigation be pursued through the widest possible range of conditions, as well as throughout the year, since the extremes of winter are often of paramount importance. These are recorded most strikingly in the timber-line, which is marked by bizarre and contorted forms of dwarf trees so aptly termed *Krummholz,* or elfin wood.

The first investigator to deal experimentally with the effects of the alpine climate was Bonnier (1895). He came to the conclusion that the characteristic dwarfing was due primarily to greater light intensity, reinforced by a drier atmosphere and lower temperature. He made no measurements of the various factors, and carried out no physiological studies, so that his views rested upon observational data alone. With full recognition of the necessity of factor measurements and functional studies, Clements (1907) carried on a series of investigations in the Pikes Peak region from 1900 to 1906, which were designed to test Bonnier's conclusions. He found no effective differences in light in the range of 8,000 feet from the grass land at the foot of the mountains to the alpine meadows of the summits. Water relations proved to be the most decisive, in conjunction with wind and reduced pressure, while temperature was second in importance. Much of the effect of the latter was ascribed to its indirect action

in rendering the water non-available at a time when winter winds exerted a marked effect upon the water loss from the plant.

Winds are apparently important in the determination of the location of timberline in the Pikes Peak region, as is indicated by the fact that the tension line rises to higher levels in places protected from the action of northerly winds than on exposed slopes, and also by the wind-contorted dwarfs ranged at the tree line.

That winter conditions are of prime importance in determining the distribution of timber seems to be indicated by the similarity between the northward and upward distribution of trees, if one understands that by winter conditions is meant not only the actual conditions prevalent during the winter months, but also the length of the winter period. Bates (*loc. cit.*) feels that the conservation of water and radiant energy is a physiological factor of great importance to dominants in any zone, and uses determinations of sap density made in December as a criterion of the upward distribution of several species. If distribution is a result of water relations, a higher range would mean increased xerophytism; and Gates (1914) has shown the importance of winter conditions for bog xerophytes. Physiological investigations of conditions in plant zones certainly should not be confined to the summer period; the winter season may well be a vital and determining factor.

The following study was undertaken in the hope of increasing our physiological knowledge of conditions in the different zones of plant growth throughout the year.

METHODS.

Engelmann spruce (Picea engelmanni) occurs in the Pikes Peak region from the base of the mountains at 6500 feet elevation to timberline at 11500 feet. It is a dominant above the 9000-foot level. Above this zone the trees are smaller and more scattered; below they are restricted to the vicinity of streams and are found as scattered groups at the lower levels. Since this tree is one of the forest dominants, and because of the extreme altitudinal range, it was chosen for the subject of this study.

Four stations were selected for making the collections: Shelter Rock, located in Engelmann Cañon near Ruxton Brook

at an altitude of 7200 feet; Half Way, similarly situated with respect to the cañon and brook, at an altitude of 8800 feet; Timberline, located on the north slope of an alpine ridge at 11300 feet; and Krummholz, near Timberline Station at an altitude of 11500 feet. At the two lower stations there was little exposure to wind action but full light exposure. These stations, being in a cañon, were subject to considerable cold air drainage and while they developed before the others, the development was not as early as might have been expected from the temperature averages given by Robbins at these altitudes, (1917). Krummholz was completely exposed to wind, the effects of which could be seen in the extended growth to leeward of the dwarf trees. Timberline Station was largely protected against wind, so that the soil was well covered with snow during the winter season. All stations were selected for full light exposure.

Leaves were collected at Shelter Rock from a single tree about 60 feet in height; at the other stations several trees were used. Care was taken in every case to secure leaves with full light exposure, i.e. from twigs growing on the south side of trees which were subject to no shading. Effort was made to secure material at about 20 feet from the ground; but this was not possible, of course, in the Krummholz, where the total height of the trees was not over six feet. Krummholz leaves were collected from twigs with the same light exposure and position, relative to the height of the tree, as at the other stations.

Only the youngest leaves on the trees were collected. These were clipped from the tips of the twigs, placed in pint fruit jars in an atmosphere of chloroform vapor, and artifically cooled during the warmer seasons by placing in a portable ice chest. The age of the leaves of any sample is thus the time between the date of collection and the preceding spring, when the leaf buds expanded. At the end of a thirty-six-hour period of treatment with chloroform vapor the sap was expressed in a well-tinned chamber, 35 mm. in diameter, by means of a screw press exerting a pressure of about 150 kilos per square centimeter. The sap thus obtained was immediately tested.

Since the work of Dixon and Atkins (1913) has shown the desirability of treating plant tissue with chemicals or of sub-

jecting it to low temperatures before expressing the sap, an attempt was made to freeze the spruce leaves after the method of Gortner and Harris (1914); but it soon appeared that temperatures attainable by a salt-ice mixture were not low enough to produce an effect on the leaf tissue during the winter season, when similar temperatures commonly occur in the plant habitat. This condition was noted by Newton (1922) in winter wheat after the autumn hardening period, and successive and prolonged freezing in a calcium chloride-snow mixture was found to have little effect upon the permeability of the leaf tissue. As liquid air was not available, a thirty-six-hour treatment with chloroform vapor, as mentioned above, was employed, the leaves being kept in refrigeration during the period to reduce enzyme action.

The solubility of chloroform in water is 7.10 grams per liter at 20° (Seidell, 1911). A chloroform solution saturated at room temperature would give a 0.0595 molar solution and show a freezing point depression of approximately 0.1°. Determinations gave an average depression of 0.102°. All freezing point depressions given in this paper have been corrected by subtracting 0.1 from the observed value.

That the chloroform treatment made no significant difference in the results here recorded is shown by reference to Table 1, which gives the readings made from duplicate samples

TABLE 1.

A comparison of the data obtained from sap expressed from Chloroform-treated and from frozen leaves. August 6, 1923.

Station.	Density.	Index of Refraction.	Osmotic Pressure.	Electrical Conductivity	Initial Acidity. pH
Timberline.					
(chloroform-treated)	1.0326	1.3448	11.122	6.715	3.40
(frozen)	1.0303	1.3456	11.173	6.690	3.42
Krummholz.					
(chloroform-treated)	1.0340	1.3454	11.940	6.540	3.05
(frozen)	1.0306	1.3444	11.257	6.270	3.10

collected August 6, and subjected to freezing and chloroform treatment. The titration curves obtained from these samples are given in Table 20 and Figure 17.

Immediately after cutting the leaves from the twigs, a representative sample was placed in a vial with rubber stopper, and the water content was determined by drying to constant weight at 98°. A second sample of the leaves was thrown into boiling 95% alcohol with 1% ammonia immediately after cutting from the twigs in the field, after the method of Davis and Daish (1913). This was brought to the laboratory and the alcohol-ammonia mixture allowed to evaporate in the air at room temperature. The leaf residue was dried to constant weight at 98°, ground to a fine powder, and used for carbohydrate determinations, Matthews' modification of Benedict's method being employed in the work (Matthews, 1919).

The water and carbohydrate content of the leaves were determined together with the following properties of the sap: density, refractive index, osmotic pressure, electrical conductivity, initial acidity, and titration curves. Polariscope determinations gave unsatisfactory results and were discontinued.

WATER CONTENT.

The water content of the leaves, based on the original weight, is given in Table 2, and the results are graphed in Figure 1. From March, when the work was started, to June the leaves from Shelter Rock and Half Way show a consistent and steady drying out. This desiccation continues to the end of the study of the older leaves, i. e. to July, at Shelter Rock; but at Half Way there is a marked increase in water content in July. The leaves from Timberline show a varying water content but a general decline during the winter months followed by a slight increase in June. Krummholz has a leaf water content strikingly lower than that found at the other stations studied, but shows a marked rise during June and July. The gradual desiccation of the leaves at Krummholz does not proceed, during the late winter, with any greater speed than occurs at the lower and more protected stations.

Young leaves were secured at Shelter Rock in June, but at the other stations for the first time in July, so that the relative position of these early points shows not so much the effect

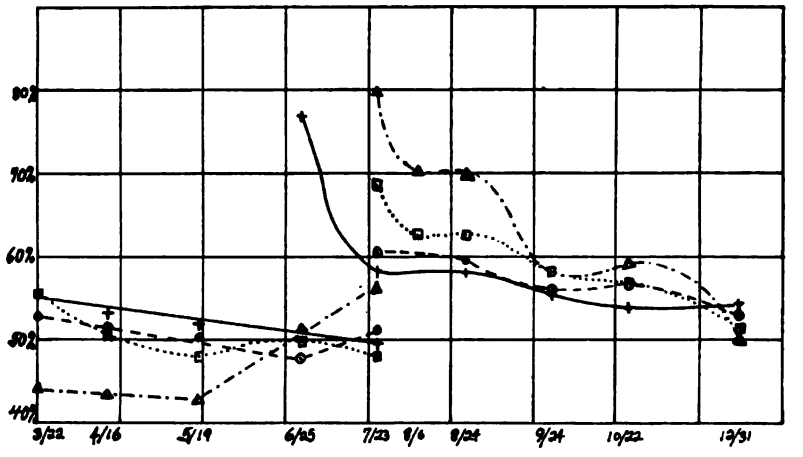

Figure 1.
Water Content of Leaves.
Days plotted as abscissae, percentage of water as ordinates.
+ ——— Shelter Rock. ⊙ - - - - Half Way. □ · · · · Timberline. ▲ – – – Krummholz.

of habitat as the difference in the age of the leaves. Thus the leaves taken from Shelter Rock in June were about as old, i. e. as much expanded from the bud, as those taken from Krummholz in July, and both agree in showing a very high water content. Had the leaves from Timberline and Half Way been studied in as young a condition as those from Shelter Rock and Krummholz, they would probably have shown a water content as high as that of the latter. There is a consistent fall in all the curves throughout the summer period. Krummholz shows greater desiccation during the fall, and, judging from the curves of the older leaves, would continue this decline in moisture content until a minimum was reached, when the rate of water-loss would be similar to that occurring at the more protected stations no matter what the exposure to which the Krummholz leaves were subjected.

That the loss of moisture from the leaf is due to the evaporation and not to the use of water in a chemical reaction, as by the hydrolysis of the polysaccharids, seems certain, in view of the fact that the average molecular weight of the dissolved substances in the sap increases as the season progresses. This agrees, as is shown later, with the results of Tottingham

TABLE 2.

WATER CONTENT OF SPRUCE LEAVES.

(Percentage of original weight.)

Stations.	March 22.	April 16.	May 19.	June 25.	July 23.	August 6.	August 24.	Sept. 24.	Oct. 22.	Dec. 31.
Shelter Rock	55.2	53.3	51.9	50.1	49.7					
(young)				77.0	58.4		58.0	55.4	53.9	54.5
Half Way	52.8	51.5	50.3	47.7	51.1					
(young)					60.6		59.5	56.0	56.7	53.1
Timberline	55.8	50.6	48.0	50.0	48.0					
(young)					69.0	62.9	62.9	58.1	56.8	51.6
Krummholz	44.2	43.4	42.7	51.5	56.1					
(young)					80.0	70.4	70.2	58.0	59.2	50.2

(1923), who found that low temperatures tended to increase the formation and storage of polysaccharids.

The water content of the young leaves of Engelmann spruce falls rapidly to the autumnal condition, and this decrease is independent of altitude, zone, or slope. Initial desiccation seems to proceed more rapidly at the lower altitudes than at the higher, but the total amount of water-loss is in the reverse order. During the winter, desiccation proceeds slowly but continuously at all altitudes and exposures studied.

DENSITY.

Bates (1923) suggests the physiological importance of the density of tree sap, and considers the zone of dominance to be partially determined by this property. He determined the total soluble matter contained in the tops of seedlings of western yellow pine, Douglas fir, and Engelmann spruce, and found that in December Engelmann spruce contained sap of high density. He suggests that the occurrence of the spruce zone at high elevations and the development of this tree up to timberline may be explained on this basis, because high density is probably correlated with high solid content and reduced vapor pressure; hence reduced transpiration, which in turn would favor increased leaf temperatures and heightened photosynthetic activity.

Sap densities were obtained by means of the Westphal balance. Since the densities of saturated chloroform solutions at 17° and 29.4° are 1.00284° and 1.00280° respectively, (Seidell, 1911), the error due to the presence of this substance is below the experimental error to be expected here; hence no corrections for the dissolved chloroform have been made.

Table 3 gives the observed results together with the temperature at which the observation was made and the values corrected to 20° on the assumption that the rate of change of density with temperature is the same for sap as for pure water. These corrected values are graphed in Figure 2. It will be seen that, in general, the density of sap from the older leaves decreases during the spring and early summer and that this decrease was especially marked in the leaves from the Krummholz. The young leaves show a general rise in density throughout the period of study.

TABLE 3.

DENSITY.

Station	May 19. observed	d^{20}	June 25. observed	d^{20}	July 23. observed	d^{20}	August 6. observed	d^{20}
Shelter Rock.	1.0865 (20)	1.0865	1.0730 (16)	1.0722	1.0781 (18)	1.0777		
(young)			1.0380 (16)	1.0372	1.0599 (18)	1.0595		
Half Way.	1.0789 (20)	1.0789	1.0720 (16)	1.0712	1.0699 (17)	1.0693		
(young)					1.0510 (17)	1.0504		
Timberline	1.0885 (20)	1.0885	1.0775 (16)	1.0767	1.0790 (18)	1.0786		
(young)					1.0465 (18)	1.0461	1.0326 (16)	1.0318
Krummholz	1.1038 (20)	1.1038	1.0760 (16)	1.0752	1.0685 (19)	1.0683		
(young)					1.0343 (18)	1.0339	1.0340 (15)	1.0330

TABLE 3 (continued).

Station	August 24. observed	d^{20}	September 24. observed	d^{20}	October 22. observed	d^{20}	December 31. observed	d^{20}
Shelter Rock. (young)	1.0610(16)	1.0602	1.0665(18)	1.0661	1.0789(18)	1.0785	1.0880(25)	1.0889
Half Way. (young)	1.0618(16)	1.0610	1.0658(18)	1.0654	1.0752(18)	1.0748	1.0888(25)	1.0897
Timberline. (young)	1.0488(15)	1.0478	1.0706(18)	1.0702	1.0783(18)	1.0779	1.0905(25)	1.0914
Krummholz. (young)	1.0444(15)	1.0434	1.0675(18)	1.0671	1.0760(18)	1.0756	1.1004(25)	1.1013

Observed values are given in the first column under each date of observation followed by the temperature, in brackets, at which the values were obtained. The values corrected to 20°, recorded under d^{20}, are computed as follows:

$$d^{20}=d^{t}+d_{w}^{20}-d_{w}^{t}$$

Where d^{t} is the observed denstiy of the sap, and d_{w}^{20} and d_{w}^{t} are the densities of water at 20° and the temperature of observation respectively.

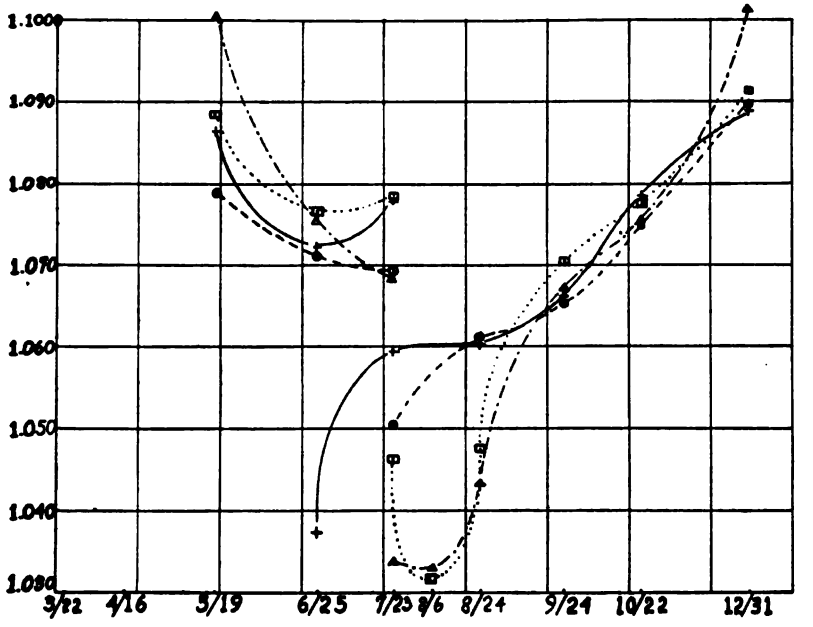

Figure 2.
Density of Sap at 20°.
Abscissae are days, ordinates densities.
+ ——— Shelter Rock. ⊙ - - - - Half Way. ⊡ ····· Timberline. ▲ -·-·- Krummholz.

Miyaks (1902) found a great increase in sugars in evergreen leaves during the fall and early winter, and this might be regarded as a cause of the rapid increase in density of the sap in the present case. That this is probably not the case may be seen by comparing the graphs for density and water content. It will be seen that when the water content is decreasing the sap density is increasing, owing to the concentration of the sap solutes. This increase in density is solely due to the transpiration loss from the leaves, since the same density relationship is observed in the concentration of a sugar solution. This curve is shown in Figure 3, in which the percentage of water is plotted against the density for sucrose solutions and for representative samples of sap. This shows no evidence of anything but desiccation. This curve neither disproves nor confirms the presence of chemical changes in the sap solutes, since sucrose and invert sugar follow the same density percentage curve.

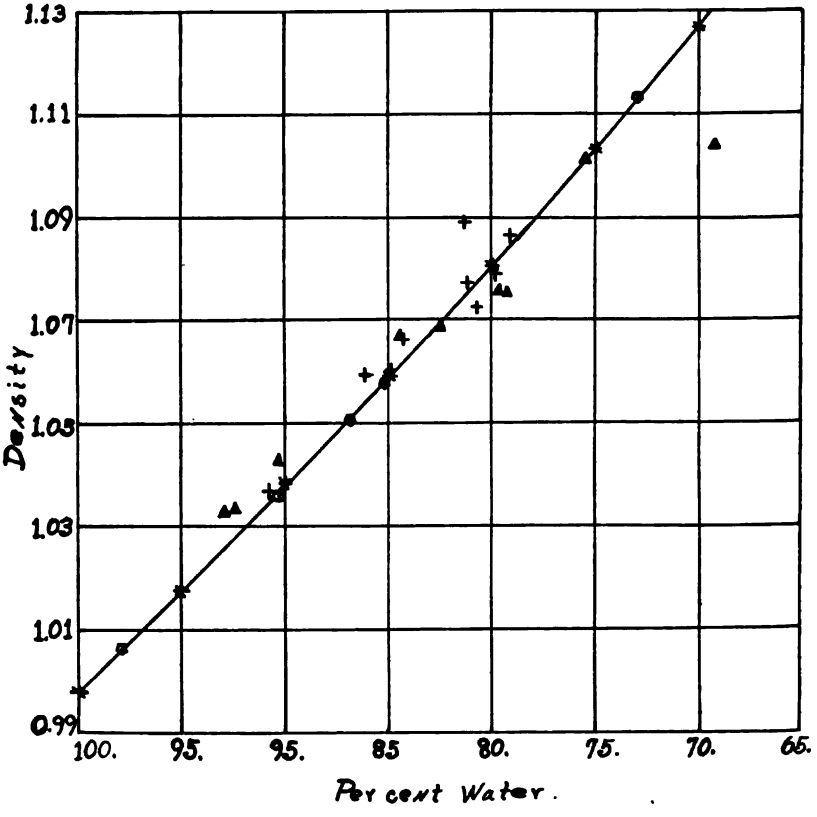

Figure 3.
Density and percent of water in sap and sugar solutions.
Percent water plotted as abscissae, density as ordinates.
The line is the density-water-content curve for sugar solutions.
✳ Sucrose. solution ⊙ Invert sugar solution. + Shelter Rock sap. △ Krummholz sap.

INDEX OF REFRACTION.

Table 4 gives the determinations of the index of refraction, and these values are graphed in Figure 4. It will be seen that the curves are very similar to those of density. Since this value is very easily obtained by the use of any standard refractometer, and the determination requires but a drop of material, it should be employed more extensively by ecological workers. With comparatively little labor it would be possible to make a large and complete series of determinations and thus to check Bates' hypothesis as to the value of sap

TABLE 4.

INDEX OF REFRACTION.

Station	March 22.	April 16.	May 19.	June 25.	July 23.
Shelter Rock.	1.3660 at 18°	1.3667 at 17.8°	1.3689 at 20°	1.3658 at 20°	1.3653 at 21.5°
(young)				1.3487 at 20°	1.3565 at 21.5°
Half Way.	1.3680 at 18°	1.3669 at 17.8°	1.3659 at 20°	1.3659 at 20°	1.3621 at 21.5°
(young)					1.3526 at 21.5°
Timberline	1.3672 at 18°	1.3735 at 17.8°	1.3688 at 20°	1.3655 at 20°	1.3675 at 22°
(young)					1.3517 at 22°
Krummholz	1.3840 at 18°	1.3852 at 17.8°	1.3855 at 20°	1.3684 at 20°	1.3629 at 22°
(young)					1.3460 at 22°

Station	August 6.	August 24.	September 24.	October 22.	December 31.
Shelter Rock. (young)		1.3589 at 20°	1.3599 at 22.5°	1.3675 at 22°	1.3648 at 25°
Half Way. (young)		1.3585 at 20°	1.3583 at 22.5°	1.3646 at 22°	1.3710 at 25°
Timberline. (young)	1.3448 at 21.4°	1.3525 at 20°	1.3599 at 22.5°	1.3660 at 22°	1.3722 at 25°
Krummholz (young)	1.3454 at 21.4°	1.3496 at 20°	1.3597 at 22.5°	1.3680 at 22°	1.3750 at 25°

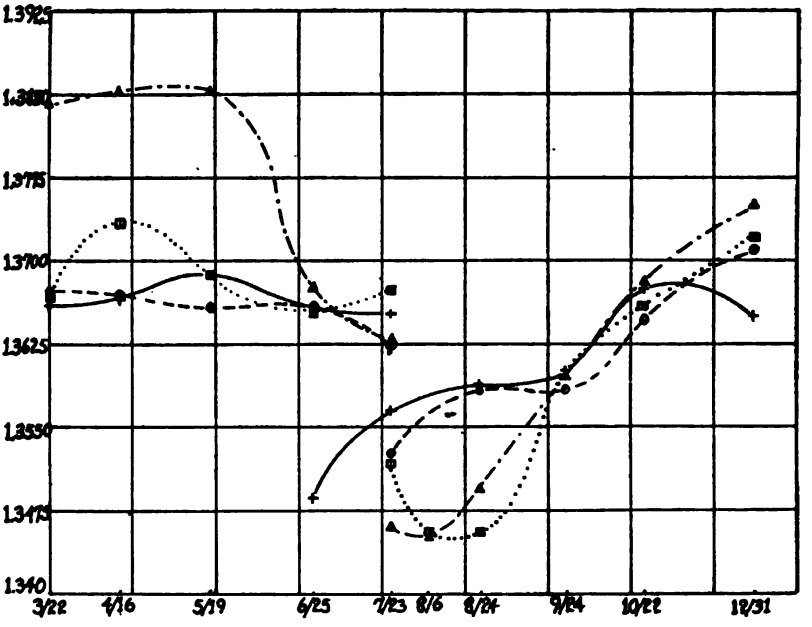

Figure 4.
Index of Refraction of Sap.
Days are plotted as abscissae, refractive index as ordinates.
+ —— Shelter Rock. ⊙ - - - - Half Way. ⊡ ····· Timberline. ▲ — · — Krummholz.

density for dominant trees. This agreement between density and the index of refraction may be shown by the specific refraction, computed according to the Gladston-Dale formula, $\frac{n-1}{d}$ where n is the observed index of refraction and d the observed density. The results are as follows:

Shelter Rock.	Half Way.	Timberline.	Krummholz.	
.3394	.3391	.3391	.3487	
.3410	.3413	.3395	.3419	
.3390	.3384	.3409	.3400	
.3361	.3413	.3362	.3348	
.3365	.3354	.3340	.3341	
.3383	.3376	.3357	.3341	
.3378	.3361	.3368	.3348	
.3408	.3391	.3365	.3377	
		.3400	.3425	
.3386	.3385	.3376	.3387	Average.

WATER CONTENT OF SAP.

The water content of the expressed sap was determined indirectly from the refractive index. The index of refraction and the percentage of solids were determined for five samples of sap and also for three dilutions of one sample. These data are recorded in Table 5, together with similar data for sucrose

TABLE 5.

Index of refraction and percent of solids in spruce sap and in sucrose solutions.

Material.		Index of Refraction (20°)	Percent Solids.*
Spruce Sap		1.3648	18.02
" "		1.3710	21.22
" "		1.3722	23.53
" "		1.3750	25.15
Sucrose Solution		1.3330	00.00
" "		1.3344	1.00
" "		1.3358	2.00
" "		1.3372	3.00
" "		1.3475	10.00
" "		1.3637	20.00
" "		1.3721	25.00
" "		1.3810	30.00
Dilutions of Sap.			
Percent Sap.	Density.		
100.	1.0800	1.3672	19.87
86.6	1.0670	1.3619	17.20
77.41	1.0632	1.3580	15.37
46.15	1.0376	1.3476	9.16
35.23	1.0230	1.3410	7.00

*Based on the original amount of solid material obtained by evaporating to constant weight at 98°.

solutions computed for 20° from the data tabulated in Van Nostrand's Chemical Annual (Olson, 1920). The curves drawn from the value for the index of refraction of water through the locus of the points is shown in Figure 5. Gortner and Hoffman (1922) have used the method of determining the

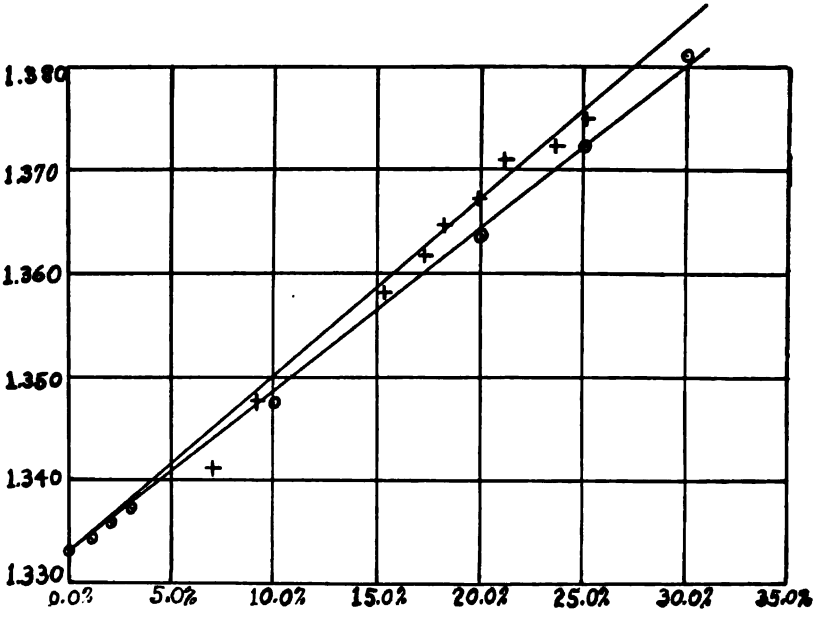

Figure 5.
Refractive index and percent dry solids in spruce sap and in a sucrose solution. Percent solids plotted as abscissae, index of refraction as ordinates.
+ Determinations made on spruce sap. ⊙ Values for sucrose solution.

percentage of solids in expressed fluids from plant tissue by reference to sugar refractive values. This would be equivalent to the use of the sucrose curve here shown. It is evident that the determinations made from the undiluted spruce sap and those from the sugar solutions do not agree closely except at dilutions higher than occurred here. The curve made to accord with the sap values was, therefore, used; and percentage solids equivalent to the observed index of refraction was read from the graph. The percentages of water thus computed are given in Table 6 and these values are shown in the curves of Figure 6.

It will be seen that the water content of the sap agrees well with that of the leaves, the chief differences being in the curves from the young leaves from Timberline and Krummholz when rapid tissue changes might well have occurred. The same slow fall during the winter, rise in spring at the higher

TABLE 6.

Water content of the spruce sap computed from the curve of the index of refraction.

Station	3/22	4/16	5/19	6/25	7/23	8/6	8/24	9/24	10/22	12/31
Shelter Rock.	80.7	80.2	79.1	80.8	81.2					
(young)				90.8	86.2		84.9	84.4	79.9	81.4
Half Way.	79.6	80.2	80.8	80.8	83.0					
(young)					88.6		85.1	85.2	81.6	77.8
Timberline.	80.0	76.3	79.2	81.0	79.9					
(young)					89.2	93.2	88.6	84.4	80.7	77.2
Krummholz.	70.2	69.5	69.2	79.3	82.6					
(young)					92.5	92.8	90.4	84.5	79.6	75.5

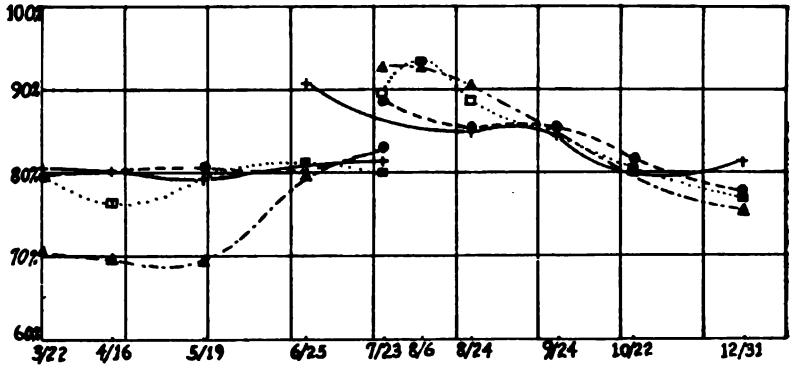

Figure 6.
Water content of Spruce sap.
Days plotted as abscissae percent water as ordinates.
+ —— Shelter Rock. O - - - - Half Way ⊡ · · · · · Timberline. △ - · - · Krummholz.

stations, and high values for the young leaves, falling to the winter level, are evident. Apparently the water content of the sap as computed from these determinations is a good measure of the leaf water-content.

OSMOTIC PRESSURE.

The osmotic pressure of plant sap is of great physiological and ecological importance (Dixon, 1914, Harris, Lawrence, and Gortner, 1916; Moore, 1917). It furnishes the plant with a means for producing sap movement, for reducing transpiration losses and hence conserving absorbed radiant energy, and for the prevention of frost injury. The osmotic pressures of the expressed spruce sap were determined by means of the freezing point depression according to the method of Gortner and Harris (1914). Readings were made until two or more agreed within 0.005°, if possible, but frequently the freezing point of the sap was raised by successive freezings, and readings could not be duplicated. The results obtained, corrected for dissolved chloroform, are given in Table 7, and the osmotic pressure values are graphed in Figure 7.

It will be seen that in spring and early summer there is a general decline in osmotic pressure, which accompanied, as would be expected, the decline in density and index of refraction. The curves for both old and young leaves are similar to those of refractive index. While these curves agree in a general way the fact, shown subsequently, that the number of

TABLE 7.

Freezing Point Depression (Δ) and Osmotic Pressure (P) of Sap.

($P = 12.060\ \Delta - 0.021\ \Delta^2$)

Station	March 22.		April 16.		May 19.		June 25.	
	Δ	P	Δ	P	Δ	P	Δ	P
Shelter Rock.	2.207	26.488	2.408	29.008	2.668	32.033	2.168	26.032
(young)							1.299	15.625
Half Way.	2.194	26.379	2.252	27.074	2.303	27.700	2.038	24.493
Timberline	2.050	24.622	2.931	35.165	2.804	33.640	2.252	27.074
Krummholz	3.223	38.672	4.141	49.376	4.041	48.507	2.398	28.794
	July 23.		August 6		August 24.		September 24.	
Shelter Rock.	2.180	26.191						
(young)	1.868	22.458			1.883	22.636	2.109	25.317
Half Way.	2.004	24.096						
(young)	1.550	18.650			1.799	21.623	1.853	22.288
Timberline.	2.164	26.012						
(young)	1.388	16.700	0.938	11.122	1.398	16.819	2.098	25.198
Krummholz.	1.887	22.686						
(young)	0.991	11.940	0.991	11.940	1.284	15.436	2.004	24.106

TABLE 7 (Continued)

Station	October 22.		December 31.	
	Δ	P	Δ	P
Shelter Rock. (young)	2.490	29.880	2.272	27.302
Half Way. (young)	2.236	26.875	2.397	28.214
Timberline. (young)	2.225	26.736	2.549	30.574
Krummholz (young)	2.228	26.756	2.782	33.432

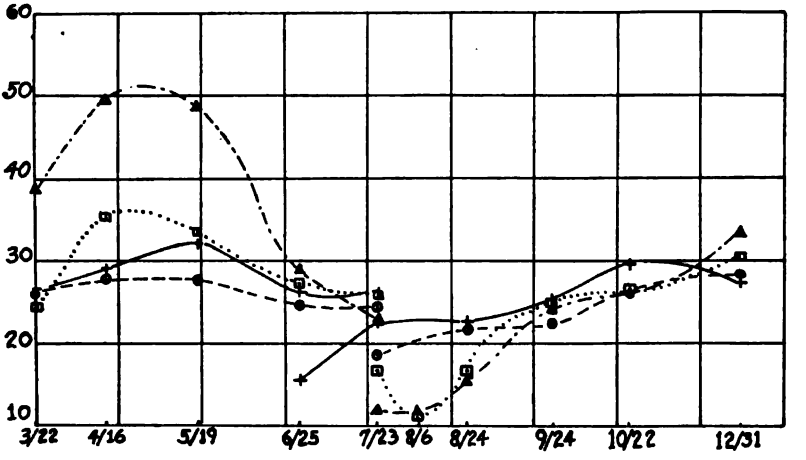

Figure 7.
Osmotic Pressure of Sap.
Days are plotted as abscissae, pressures as ordinates.
+ —— Shelter Rock. ⊙ – – – –Half Way. ⊡ ····· Timberline. △ – · – · Krummholz.

moles solute, calculated from the freezing point depression, and the water, computed from the index of refraction, give an increasing molecular weight indicates a change in kind as well as quantity of the sap solutes. It nevertheless seems that the substances present in the sap varied more in quantity than in kind.

The maximum osmotic pressure for all the leaves from all stations except Half Way occurred in April and May. These high pressures are particularly marked for the higher stations, the Krummholz curve rising far above that from any of the lower habitats. The spring maximum appears somewhat later than that given by Lewis (1920), viz. March. The high values for Krummholz are doubtless the result of desiccation by wind, in agreement with the conclusions of Ursprung and Blum (1916). During the winter season the osmotic pressure of the sap rises, in general, with the altitude of the stations, agreeing thus with the evidence of sap concentration obtained from the physical properties.

MOLECULAR WEIGHTS.

The average molecular weights of the sap solutes increased as the leaves became older. This possibly indicates that the first results of photosynthetic activity in the young leaves formed substances of comparatively low molecular weight and that later molecular condensation produced larger molecules. The values, given in Table 8, are calculated by dividing the weight of solid, taken from the refractive index readings, by the number of moles solute per 100 grams water, obtained from the freezing point depression values. This, of course, tells nothing concerning the molecular weight of individual substances, but only indicates the general nature of the processes carried out by the plant. The general trend of the values may be seen by inspection of Figure 8, in which the molecular weight curves are plotted. In the old leaves there is a fall of average molecular weight from the winter to the summer condition. Values during the summer period are variable.

There is a general rise with age in the molecular weight averages obtained from the young leaves. If these values are plotted with separate base lines and the modal curve drawn for each it will be seen (Figure 9) that, rough as this approximation is, there is shown an increased rate of change with increasing altitude of the stations. Rigorous winter conditions possibly tend to hasten the production of sap solutes of large molecular weight.

As previously shown, Figure 3, the percentage of water plotted against the density for spruce sap, glucose, sucrose, and invert sugar falls on the same curve. If then the density of glucose and sucrose solutions be plotted against the freezing point depressions, a similar curve for spruce sap should diverge from the monosaccharid toward the disaccharid curve if there is a polymerization of sap solutes. That such is the case is shown by Figure 10.

A comparison of the amount of alkali required to titrate the acid present in the sap to pH 9.0 (See Pages 29 and 51-63) and the amount of sap solutes shows that the acid becomes a smaller portion of the solutes as the season advances. This may indicate that the early photosynthetic products are acids which later are polymerized into compounds of higher molec-

TABLE 8.

Average molecular weight of solutes in spruce sap.

Station	3/22	4/16	5/19	6/25	7/23	8/6	8/24	9/24	10/22	12/31
Shelter Rock.	201.5	190.7	184.4	204.0	197.6					
(young)				145.3	160.2		175.8	163.0	187.7	187.1
Half Way.	227.0	203.6	191.9	170.3	190.2					
(young)					154.6		181.2	174.4	177.6	221.2
Timberline	227.0	197.2	174.2	173.4	216.3					
(young)					162.4	144.6	169.7	164.0	199.8	215.7
Krummholz	245.1	197.1	204.8	202.7	207.9					
(young)					152.7	143.6	153.3	170.2	214.1	216.7

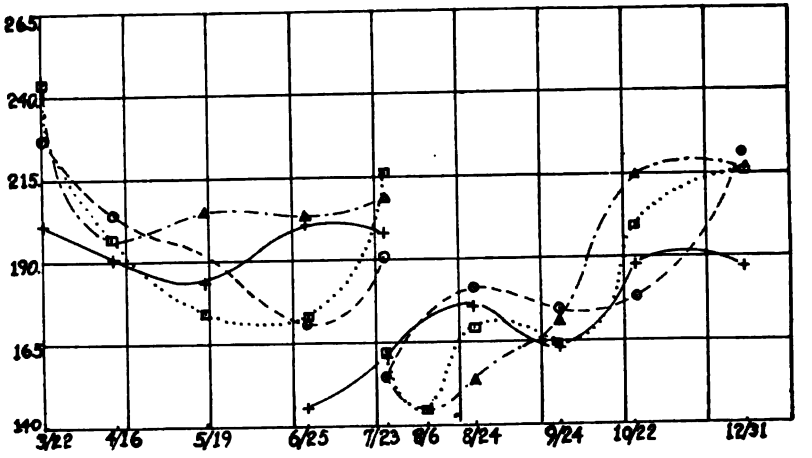

Figure 8.
Average molecular weights of Sap Solutes.
Days plotted as abscissae, average molecular weights as ordinates.
+ —— Shelter Rock. ⊙ – – – –Half Way. ⊡ · · · · · Timberline. △ · – · – Krummholz.

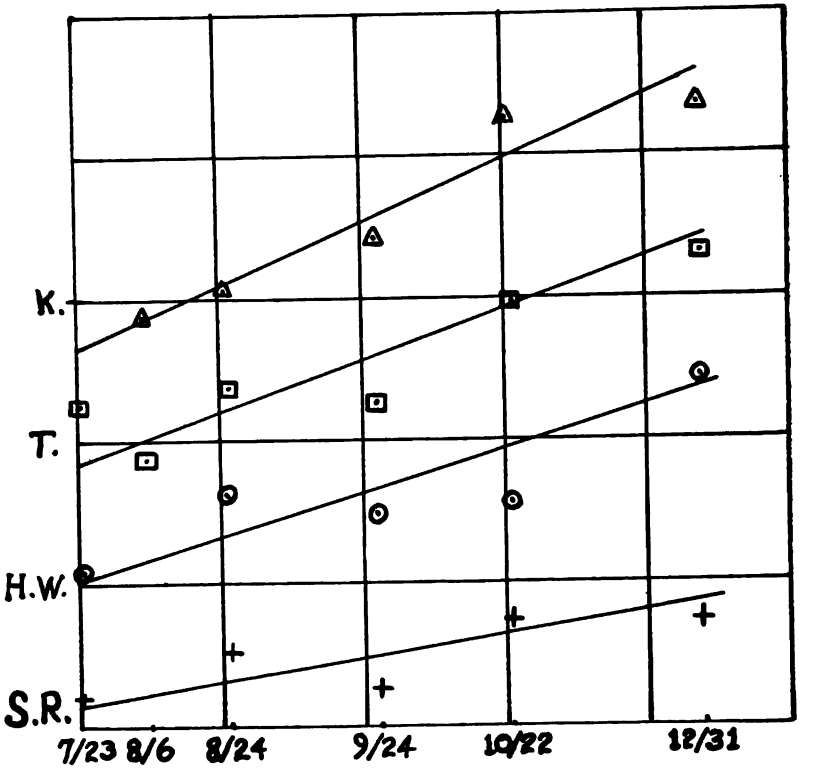

Figure 9.
Increase in molecular weight of solutes in sap from young leaves.
+ —— Shelter Rock. ⊙ – – – Half Way ⊡ ····· Timberline △ — –Krummholz.

The numbers of days are plotted as abscissae, the molecular weights as ordinates, the base line of 150 being taken on the line indicated for each station. Fifty units per square.

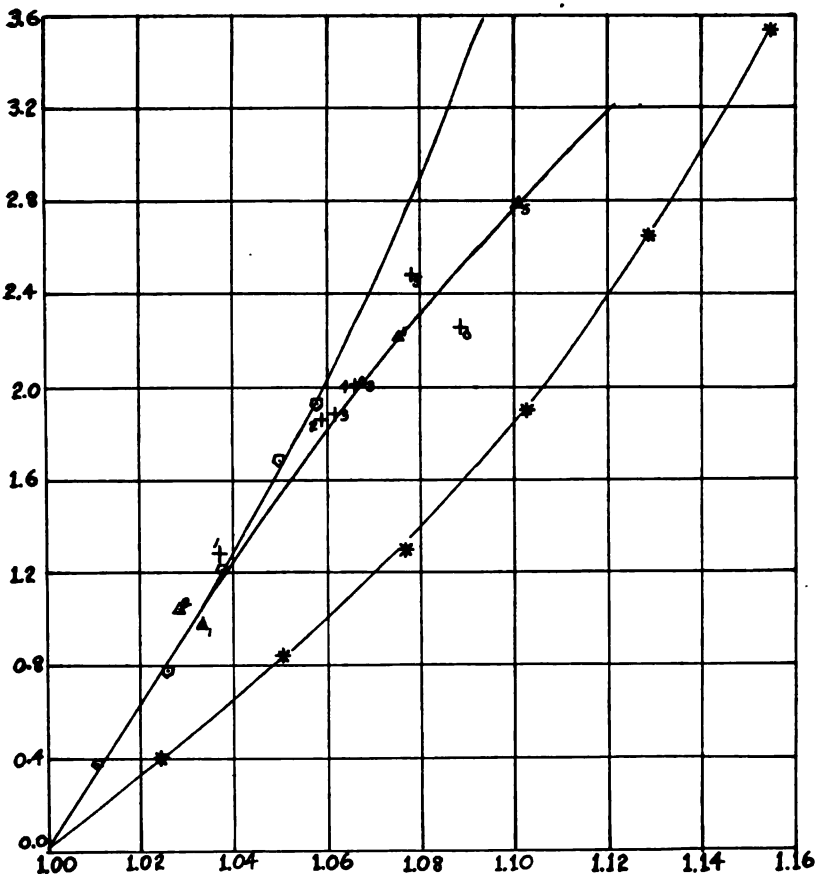

Figure 10.
Change in molecular weight of sap solutes.
Densities plotted as abscissae freezing point depression as ordinates.
Shelter Rock Sap. (young leaves) Krummholz Sap. (young leaves)
⊙ Glucose. (Values taken from Jones and Getman, 1904)
✳ Sucrose. (Values taken from Jones and Getman, 1904)

ular weight. This seems confirmatory of the statement made above, that the conditions of the higher habitats tend to increase the production of sap solutes of high molecular weight.

ELECTRICAL CONDUCTIVITY.

The electrical conductivity was taken by the usual methods, the sample of sap being kept in a thermostat at 25° with a variation of ±0.1°. The values given are the specific conducti-

vities in mhos x 10^3 computed from the observations made in duplicate. Following Atkins (1916) the electrical conductivity is frequently taken as a measure of the inorganic material present in the sap. This assumption is untenable in the present case, because the electrometric titration curves, given below, show the presence of organic acids which must have an appreciable conductance. Moreover Loeb (1922) found conductivities and titration curves of pure 1% colloidal solutions of gelatin and other substances which are comparable with those given in this study, so that it is probable that colloids account for a portion of the observed conductance. Since the conductance of colloidal solutions varied markedly with the pH and the location of the isoelectric point, variable conductivity curves are to be expected in expressed tissue fluids where they are the resultant of content of organic and inorganic solutes and of colloids.

The great variability, high mid-summer values, and low winter readings are conspicuous in the results given in Table 9 and Figure 11. In a general way the electrical conductivity varied with the water content of the leaves except in the very young condition, where the water content was high and conductivity low. This agreement indicates that the great addition of substances of high conductance occurred in the summer shortly after the rapid expansion of the leaves, and that during the rest of the first year there was, in general, a somewhat greater removal than addition of these from the sap, even during the periods when the leaf water-content was also falling.

From Figure 11 it will be seen that the summer rise in conductivity of the sap from the new leaves occurred earlier at the lower stations than at the higher, corresponding to the relative season, and, for the same reason, the autumn decline took place earlier at the higher elevations. The autumn decline in conductivity occurred at the time when the water content of the leaves was decreasing and must represent a removal of substances of high conductance from the cell solution. It seems probable that the comparatively slight vernal fall in conductivity results, partially at least, from the rapid use of the inorganic solutes in tissue building, but that the pronounced autumn decline, following the period of rapid absorption and transpiration of mid-summer, is a preparation

TABLE 9.
Electrical Conductivity of Sap.

Station	Mar. 22	Apr. 16	May 19	June 25	July 23	Aug. 6	Aug. 24	Sept. 24	Oct. 22	Dec. 31
Shelter Rock.	8.31	7.86	8.16	7.78	7.48					
(young)				7.32	9.82		10.08	10.19	9.02	8.37
Half Way.	6.97	6.72	7.04	7.39	7.69					
(young)					9.33		10.16	9.60	8.25	6.64
Timberline.	7.14	7.20	8.84	6.71	5.17					
(young)					7.69	6.71	9.77	7.72	7.15	5.89
Krummholz.	7.22	7.30	7.05	7.02	6.77					
(young)					6.42	6.54	8.96	7.55	7.82	8.23

Conductivity in mohs x 10^3.

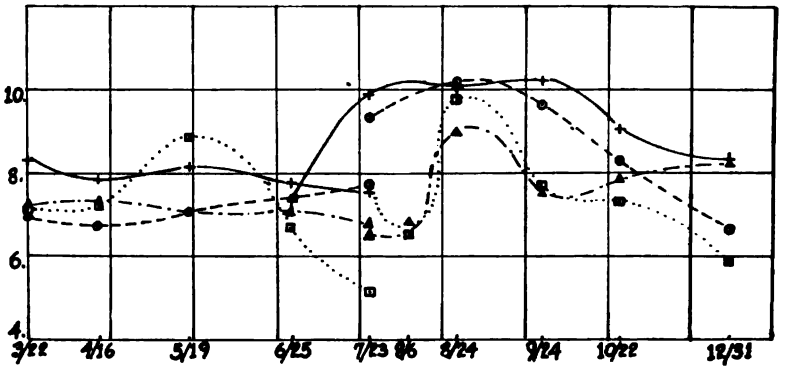

Figure 11.
Electrical Conductivity of Sap.
Days are plotted as abscissae, specific conductivities as ordinates.
+ ——— Shelter Rock. ⊙ – – – Half Way. ⊡ ····· Timberline. ▲ – · – · Krummholz.

for winter. Harvey (1918) has suggested that winter hardening consists in part of the alteration of the cell proteins, so that precipitation will not occur when incipient freezing increases the salt concentration of the cell solution. Engelmann spruce possibly meets this situation by reducing the salt content of the sap to enhance the effect of protein hydrolysis or to make such change necessary.

TOTAL CARBOHYDRATES AND TANNINS.

The dry leaf material left from the evaporation of the alcohol-ammonia mixture was ground to a fine powder. One-gram samples were boiled for three hours with 50 cc. 1% hydrochloric acid in flasks fitted with reflux condensers. Preliminary tests showed that this treatment resulted in complete hydrolysis of the carbohydrates and that no appreciable loss in these substances occurred. The acid was neutralized with solid sodium carbonate, the liquid filtered off, and the residue on the filter washed with 25 cc. boiling water. The total filtrate was made up to 100 cc., from which 25 cc. samples were used for the determination of the total reducing power. To remove the tannins 10% gelatine solution was added drop by drop to the remaining filtrate until no further precipitation occurred, the precipitate filtered off, and 50 cc. of this filtrate made up to 100 cc. for a second determination of the reduction, for which a 50 cc. portion was employed.

The reducing substances present were estimated by means of the Bertrand modification of the Munsen-Walker method as given by Matthews (1919). It was found that, at the altitude of Colorado Springs, a bath boiling at 116° brought the test solution to the boiling point in considerably less than the required 4 minutes, and also was likely to produce violent boiling and foaming of the solution. A bath with boiling point of 106° was found to bring about the boiling of the 100 cc. test solution in 4 minutes and was, therefore, employed in this work. Boiling was then continued for 4 instead of the specified 2 minutes (Matthews, *loc. cit.*). Determinations made on solutions of known sugar content showed that in this procedure 83.9 mg. copper correspond with 50 mg. invert sugar. This is but 85% of the value as given by Matthews as the invert sugar equivalent of this weight of copper. For absolute values the results here given should be increased according to these numbers; but in this paper, since the relative values only are considered, no such correction has been applied.

Table 10 gives the values as percentage invert sugar of dry weight. The values computed from the reduction of the tannin-free material are given under carbohydrates. The difference in reduction between this and extract untreated with gelatine solution is used for computing the tannins, values given being in the form of invert sugar equivalents of reduced copper.

The curves for total carbohydrates are given in Figure 12. It will be seen that during the winter the total carbohydrates vary in the order of the altitude of the stations. There is a rise in May and also in September at all stations, the autumn rise being especially conspicuous at the higher elevations. The carbohydrate content of the young leaves is low, as would be expected from the high water content and the rapid growth taking place at this season. The similarity of the autumn and early winter curves for the young leaves with those of osmotic pressure suggests that most of the reducing substances present are in solution, and that electrolytes did not produce the high osmotic pressures and densities observed at this season. The agreement of values for carbohydrates and total solids shows that variations in the solid content of the sap were largely due to reducing substances.

TABLE 10.
Total Carbohydrates and Tannins in the Leaf.

Station.	April 16. C.	April 16. T.	May 19. C.	May 19. T.	June 25 C.	June 25 T.	July 23. C.	July 23. T.	August 24. C.	August 24. T.	Sept. 24. C.	Sept. 24. T.	Oct. 22. C.	Oct. 22. T.
Shelter Rock	17.5	0.22	24.0	0.22	24.7	0.54	18.12	0.10						
(young)					17.09	0.89	17.78	0.43	15.17	2.63	21.20	0.66	21.13	0.54
Half Way.	19.9	0.54	23.6	0.36	23.42	0.54	20.26	0.21						
(young)							17.02	0.66	17.57	0.66	21.20	0.78	20.90	0.49
Timberline.	22.1	0.61	25.27	0.60	20.00	0.37	23.34	0.38						
(young)							18.15	0.08	17.63	2.45	24.25	0.78	24.35	0.90
Krummholz.	23.1	1.76	23.6	0.60	21.2	0.49	20.83	1.00						
(young)							15.98	0.54	19.32	0.54	25.66	1.47	26.72	0.65

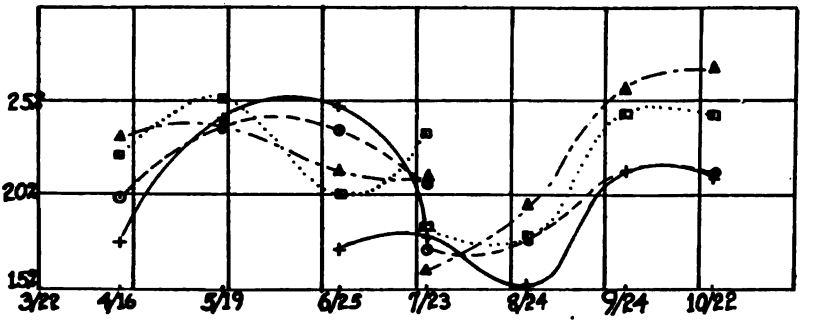

Figure 12.
Total Carbyhydrates.
Figure.
Total Carbohydrates.
Days are plotted as abscissae, percentage carbohydrates as ordinates.
+ —— Shelter Rock. ⊙ - - - - Half Way. ⊡ ····· Timberline. △ - - · - Krummholz.

The tannin present appears very variable. There seems to be a minimum during the summer months and a maximum during the early autumn.

STRUCTURAL MATERIAL.

The fact that the water content did not always agree with the variations in density may indicate a changing balance between the structural material of the tissue and the sap solutes. If there were some way to follow the change of structural material, then such an hypothesis could be verified or disproved. In order to get an approximation, with the data at hand, the following method was adopted. The total leaf solids were determined from the water content. The percentage of the total solids represented by the sugars and tannins, as determined from the reduction of copper, was computed from the invert sugar equivalents of the reduced copper and subtracted from the total solids. The resulting values are here considered as structural material.

A sample calculation is as follows: Shelter Rock, April 16, 1922. Water content 53.3%, carbohydrates 17.5%, tannins 0.22%. Then the total percentage of leaf solids is 100 - 53.3 = 46.7, the percentage of soluble material is 46.7 (17.5+0.22) = 8.3, and the percentage of structural material is 46.7 - 8.3 = 38.4.

The tabulated values are given in Table 11 and have been plotted against time in Figure 13, with the exception of an

TABLE 11.
Percent Structural Material.

Station	4/16	5/19	6/25	7/23	8/24	9/24	10/22
Shelter Rock.	38.4	36.4	37.4	41.1			
(young)			18.9	33.9	35.5	34.9	35.6
Half Way.	38.6	37.8	39.8	38.9			
(young)				30.7	33.1	34.3	36.9
Timberline.	38.2	38.5	39.2	39.7			
(young)				18.8	29.4	31.4	36.2
Krummholz.	42.5	43.4	38.0	34.3			
(young)				16.7	23.9	30.6	36.2

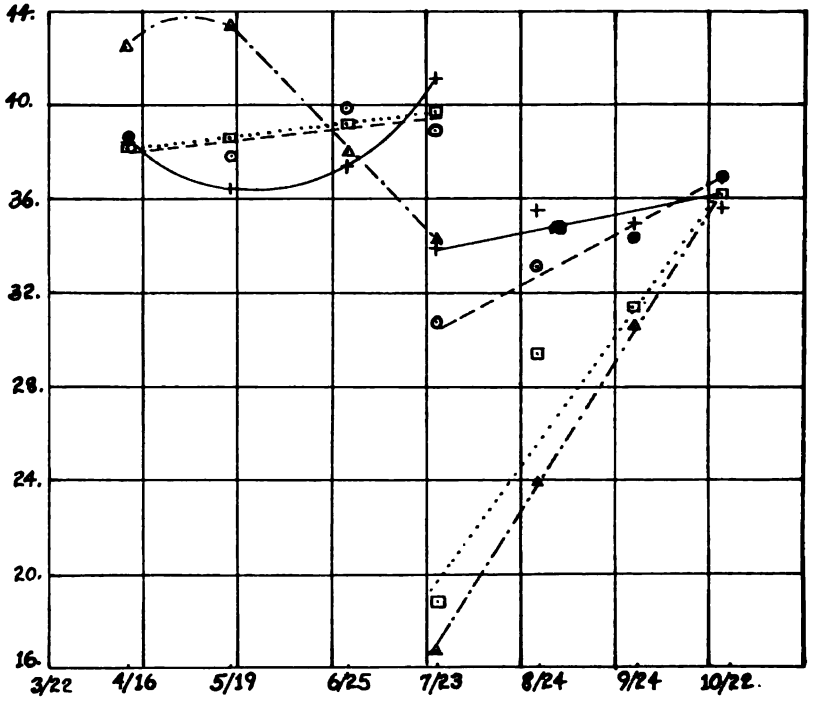

Figure 13.
Structural Material.
The days are plotted as abscissae, percent structural material as ordinates.
+ —— Shelter Rock. ⊙ – – – – Half Way. ⊡ ····· Timberline. △ · – – Krummholz.

early value for Shelter Rock obtained from leaves which had hardly escaped from the bud, for which there is no comparative value from the other stations. The values for the old leaves are comparatively high, rising during the summer except at Krummholz. Here the falling percentage of structural material is, at least partially, due to the rapid rise in water content at this period, but may also represent an actual consumption of structural substances to supply the new buds which are making rapid growth at this time. The curves show a rapid increase in structural material taking place in the young leaves. Figure 13 shows clearly that the rate of increase of structural materials is much greater at the higher than at the lower stations.

RATE OF WATER LOSS.

The water content curve for the young leaves, when plotted against time, shows a rough resemblance to a reaction curve; and hence work was undertaken to find whether it obeyed the physical law for a chemical reaction and approached the dehydration curve of a gel. Such a dehydration proceeds according to a monomolecular law of chemical reaction rate, viz. $K = \frac{1}{t} \log \frac{c}{r_t - r_\infty}$ There were several irregularities in the orginal curve which made a direct test of the law difficult, but it was found that the rate of dehydration did follow the above law when the water content was referred to the structural material content. Thus if we take the rate of change of water per gram of structural material the loss of water obeys this law with remarkable accuracy, considering that the moisture and temperature changes in the habitat are not constant, as in a controlled chemical experiment. The data are tabulated in Table 12 and graphed in Figure 14.

It is significant that the rate of water-loss is so closely-allied to the dehydration of a gel, and that the gel material is the structural material of the plant, for when the total solids are used the results are not in as close agreement with the theoretical curve. The curves of the different stations fall in the same relative positions as their altitude. Only the extremes for Krummholz and Shelter Rock are recorded. It may be significant that all the curves cross in the autumn at very nearly the same date.

TABLE 12.

Rate of dehydration of young leaves from Shelter Rock and Krummholz Stations together with theoretical values for the desiccation of colloids.

Shelter Rock.

Date.	Days.	Water.	Structural Material.	Water/Structural Material.
6/25	5	77.0	18.9	4.073
7/23	32	58.6	33.9	1.739
8/24	64	58.0	35.5	1.634
9/24	95	55.4	34.9	1.588
10/22	123	54.5	35.6	1.531
Krummholz.				
7/23	32	80.0	16.7	4.79
8/24	64	70.2	23.9	2.94
9/24	95	58.0	30.6	1.895
10/22	123	50.2	36.2	1.387

Theoretical Values.

Days.	Shelter Rock. Ratio.	Krummholz. Ratio.
15		6.91
30	2.378	5.11
60	1.701	2.99
90	1.502	1.96
120	1.444	1.465
150	1.427	1.22

Theoretical values are computed from the equation $k=1/t \log c/r_t - r_\infty$ where k is the dehydration constant, r_∞ the equilibrium ratio of water to structural material, r_t the ratio of water to structural material at any time t, and c a constant for the given station. The constants for these two stations are: Shelter Rock; k, —.01776, c, 3.25., r_∞, 1.42. Krummholz; k, —.01051, c, 8.5, r_∞, 1.0.

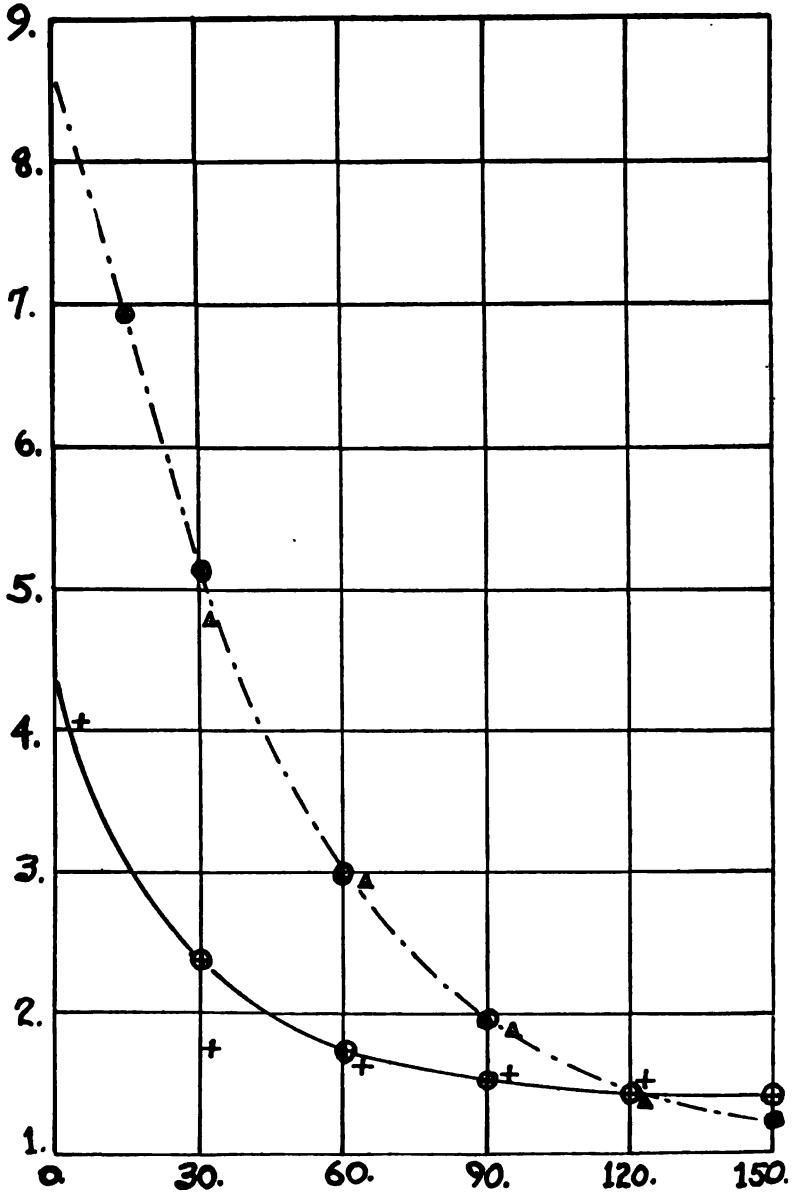

Figure 14.
Rate of Water Loss.
The theoretical and observed desiccation rate for young spruce leaves from Shelter Rock and Krummholz Stations.
Days plotted as abscissae, reaction constants as ordinates.
Solid line theoretical curve for Shelter Rock, broken line for Krummholz.
+ Observed values for Shelter Rock ⊕ Theoretical values.
▲ Observed values for Krummholz ⊕ Theoretical values.

ACIDITY.

Initial acidities are difficult to obtain in trustworthy form from spruce sap by the hydrogen electrode. It was found practically impossible to get a platinum electrode in equilibrium with the material while in the original condition. After a small amount of either NaOH or HCl had been added this difficulty disappeared. The initial acidities as recorded are thus not considered accurate, and further work is being done to determine them more accurately.

There are several causes which may account for this discrepancy in the pH value obtained in this way. There are two oxidation-reduction reactions going on simultaneously at the hydrogen electrode. One is the hydrogen ion, gaseous hydrogen oxidation potential usually considered and the other is an oxidation-reduction potential set up by the oxidized-reduced substances in the plant sap. Both of these will be effected by the amount of oxygen dissolved in the plant sap. Since oxygen is swept out of the solution by the hydrogen gas the potential will show a gradual trend. The electrode in the presence of oxygen is positive to the calomel electrode but, as the sweeping action of the hydrogen progresses, shows a falling potential and finally changes sign. On the other hand gaseous hydrogen in the presence of platinum black may be reducing an oxidizing substance, thus lowering the equilibrium potential. Unless great care is taken it is impossible to come to the same state in each determination, and for this reason the value of initial acidities would be variable. This was found to be the case in the present work. The solution of this difficulty is anticipated by the use of the quinhydrone electrode (LaMer and Rideal, 1924).

The initial acidities as obtained are given in Table 13. They show, in general, a minimum in August to September and maxima in June and December. The higher stations, though variable, are generally more acid than the lower.

Titration curves were determined by employing a 10 cc. sample of sap and adding .2N sodium hydroxide solution in 1 cc. increments. Owing to the saturation difficulties mentioned above, the acidity reading was made two minutes after the addition of the alkali solution. A Hildebrand hydrogen electrode was employed, the hydrogen stream giving about two bubbles

TABLE 13.
Initial Acidities of Sap. (pH).

Station.	March 22	April 16	May 19	June 25	July 23	August 6	August 24	Sept. 24	Oct. 22	Dec. 31
Shelter Rock	3.83	3.20	3.60	2.89	4.17					
(young)				2.20	3.90		3.81	4.14	3.86	3.66
Half Way.	3.94	3.24	3.86	2.64	4.20					
(young)					4.11		3.86	3.84	3.81	1.96
Timberline.	3.87	3.15	2.76	2.48	4.10					
(young)					3.20	3.40	3.46	3.45	3.84	2.42
Krummholz.	3.20	2.45	2.56	2.06	3.62					
(young)					3.17	3.05	3.58	4.21	3.80	1.55

per second. An electric stirrer insured constant and rapid mixing of the sample and the alkali solution. But one titration with acid was made, viz. December 31. The results of the titration are given in pH units in Tables 14 to 25, and some of the typical results are shown in Figures 15 to 19.

The titration curves of the new leaves show a marked difference from the old, as will be seen by comparing the curves in Figure 15. From pH 3 to pH 12 the old leaves show a much higher buffer action. Figure 15 represents the type of curve of the sap expressed from very young leaves and is reproduced by the curves from the higher stations in Figure 16. At this time the leaves from the lower stations show a point of inflection in the curves at pH 3 to 4, indicating the presence of some free acid. The very rapid rise of pH with the addition of alkali shows that the acidity is largely due to a free acid group. When these curves are compared with the curves of Figure 19 for December 31, it will be seen that this rapid rise in pH is probably the second one, since there is one below pH 2. This indicates that we are dealing with the acid salt of a dibasic acid.

Turning to Figure 18, made from leaves collected on August 24, it is apparent that another acid group has appeared and that now there is present a tribasic acid. This gradually disappears, and the curves, by December 31, fall into the type of the older leaves (Figure 19).

Only one titration with acid was carried out, viz. December 31. The results are given in Tables 24 and 25, and the curve is shown in Figure 19. This curve shows another very interesting phenomenon. As the amount of acid is increased the curve passes through a minimum pH and then becomes slightly more alkaline. This is probably accounted for by the presence in the sap of materials which form bases upon hydrolysis. Wendt and Clark (1923) observed a similar phenomenon in the titration of phosphoric acid with calcium hydroxide.

There is no general difference in the results from the various altitudes. The fact that in early winter and early spring the curves from all stations nearly coincide and that curves from sap expressed from leaves which had remained

TABLE 14.

Titration of a 10 cc Sample of Sap, March 22, 1923.

Shelter Rock.		Half Way.		Timberline.		Krummholz.	
NaOH	pH	NaOH	pH	NaOH	pH	NaOH	pH
cc		cc		cc		cc	
0.00	3.83	0.00	3.94	0.00	3.87	0.00	3.20
1.01	4.19	0.59	4.11	1.01	4.20	1.01	3.51
2.02	4.86	1.59	4.53	2.02	4.81	2.02	3.80
3.03	5.48	2.61	5.24	3.03	5.49	3.03	4.00
4.04	6.18	3.62	6.11	4.04	6.06	4.04	4.50
5.05	6.62	4.63	6.60	5.05	6.56	5.05	5.10
6.06	7.04	5.64	7.05	6.06	6.91	6.06	5.55
7.07	7.46	6.65	7.41	7.07	7.24	7.07	6.00
8.08	7.89	7.66	7.86	8.08	7.58	8.08	6.32
9.09	8.23	8.67	8.19	9.09	7.90	9.09	6.64
10.10	8.65	9.68	8.59	10.10	8.26	10.10	6.90
11.11	8.98	10.69	8.86	11.11	8.59	11.11	7.21
12.12	9.36	11.70	9.21	12.12	8.89	12.12	7.51
13.13	9.69	12.71	9.51	13.13	9.21	13.13	7.80
14.14	9.93	13.72	9.80	14.14	9.48	14.14	7.97
15.15	10.21	14.73	10.09	15.15	9.78	15.15	8.25
16.16	10.45	15.74	10.35	16.16	10.05	16.16	8.51
17.17	10.64	16.75	10.61	17.17	10.36	17.17	8.74
18.18	10.80	17.76	10.78	18.18	10.58	18.18	8.89
19.19	10.95	18.77	10.95	19.19	10.74	19.19	9.12
20.20	11.09	19.78	11.06	20.20	10.90	20.20	9.34
21.21	11.16					21.21	9.59
22.22	11.25					22.22	9.75
						23.23	9.96

TABLE 15.

Titration of a 10cc Sample of Sap, April 16, 1923.

Shelter Rock.		Half Way.		Timberline.		Krummholz.	
NaOH	pH	NaOH	pH	NaOH	pH	NaOH	pH
cc		cc		cc		cc	
0.00	3.20	0.00	3.24	0.00	3.15	0.00	2.45
1.01	3.67	1.01	3.78	1.01	3.64	1.01	2.60
2.02	4.35	2.02	4.37	2.02	4.13	2.02	2.89
3.03	5.26	3.03	5.22	3.03	5.02	3.03	3.30
4.04	5.78	4.04	6.00	4.04	5.98	4.04	3.86
5.05	6.30	5.05	6.50	5.05	6.52	5.05	4.31
6.06	6.81	6.06	6.88	6.06	6.93	6.06	5.21
7.07	7.27	7.07	7.27	7.07	7.33	7.07	5.70
8.08	7.44	8.08	7.65	8.08	7.67	8.08	6.35
9.09	7.73	9.09	7.98	9.09	7.96	9.09	6.80
10.10	8.40	10.10	8.34	10.10	8.24	10.10	7.12
11.11	8.70	11.11	8.65	11.11	8.50	11.11	7.54
12.12	8.95	12.12	8.96	12.12	8.65	12.12	7.83
13.13	9.38	13.13	9.25	13.13	8.95	13.13	8.04
14.14	9.68	14.14	9.64	14.14	9.18	14.14	8.31
15.15	9.85	15.15	9.89	15.15	9.52	15.15	8.56
16.16	10.16	16.16	10.16	16.16	9.71	16.16	8.75
17.17	10.39	17.17	10.36	17.17	9.91	17.17	8.98
18.18	10.55	18.18	10.63	18.18	10.16	18.18	9.15
19.19	10.72	19.19	10.77	19.19	10.34	19.19	9.36
20.20	10.86	20.20	10.90	20.20	10.48	20.20	9.67
21.21	10.95	21.21	11.01	21.21	10.60	21.21	9.83
22.22	11.06	22.22	11.10	22.22	10.75	22.22	10.06
		23.23	11.18			23.23	10.28

TABLE 16.

Titration of a 10cc Sample of Sap, May 19,1923.

Shelter Rock.		Half Way.		Timberline.		Krummholz.	
NaOH	pH	NaOH	pH	NaOH	pH	NaOH	pH
cc		cc		cc		cc	
0.00	3.60	0.00	3.86	0.00	2.76	0.00	2.56
2.20	4.66	2.20	5.49	2.20	3.36	2.20	3.06
4.40	5.95	4.40	6.51	4.40	4.96	4.40	4.05
6.61	6.85	6.61	7.42	6.61	6.10	6.61	5.09
8.81	7.75	8.81	8.44	8.81	7.06	8.81	5.99
11.01	8.53	11.01	9.25	11.01	8.25	11.01	6.78
13.21	9.15	13.21	9.95	13.21	8.92	13.21	7.62
15.41	9.77	15.41	10.46	15.41	9.62	15.41	8.38
17.62	10.22	17.62	10.81	17.62	10.22	17.62	8.93
19.82	10.50	19.82	11.06	19.82	10.62	19.82	9.53
22.02	10.73	22.02	11.21	22.02	10.89	22.02	10.00
24.22	10.90	24.22	11.38	24.22	11.10	24.22	10.40
26.42	11.06	26.42	11.50	26.42	11.26	26.42	10.84
						28.62	10.90

TABLE 17.

Titration of a 10cc Sample of Sap, June 25, 1923.

Shelter Rock, old.		Shelter Rock, young.		Half Way		Timberline		Krummholz.	
NaOH	pH	NaOH	pH	NaOH	NaOH	pH	NaOH	pH	NaOH
cc		cc		cc		cc		cc	
0.00	2.89	0.00	2.20	0.00	2.64	0.00	2.48	0.00	2.06
1.10	3.10	1.10	2.22	1.10	3.16	1.10	2.80	2.20	3.00
2.20	3.70	2.20	2.35	3.30	4.71	3.30	4.70	4.40	5.00
3.30	4.58	3.30	2.51	5.51	5.90	5.51	6.24	6.61	6.32
4.40	5.30	4.40	2.84	7.71	6.78	7.71	7.16	8.81	6.99
5.51	5.90	5.51	3.16	9.91	7.82	9.91	8.05	11.01	8.05
6.61	6.57	6.61	3.69	12.11	8.52	12.11	8.73	13.21	8.77
7.71	7.10	7.71	4.70	14.31	9.08	14.31	9.37	15.41	9.25
8.81	7.65	8.81	5.93	16.52	9.65	16.52	9.86		
9.91	8.16	9.91	7.02	18.72	10.14	18.72	10.34		
11.01	8.66	11.01	8.40	20.92	10.23	20.92	10.66		
12.11	9.06	12.11	9.15			23.12	10.87		

TABLE 17 (Continued)

Shelter Rock, old.		Shelter Rock, young.	
NaOH	pH	NaOH	pH
13.21	9.44	13.21	9.80
14.31	9.75	14.31	10.16
15.41	10.00	15.41	10.49
16.52	10.25	16.52	10.70
17.62	10.50	17.62	10.86
18.72	10.66	18.72	11.02
19.82	10.82	19.82	11.15
20.92	10.93	20.92	11.26
22.02	11.04	22.02	11.36
23.12	11.12	23.12	11.44
24.22	11.17	24.22	11.50
25.32	11.25	25.32	11.58
26.42	11.32	26.42	11.62
27.52	11.36	27.52	11.66

TABLE 18.

Titration of a 10cc Sample of Sap, July 23, 1923.

OLD LEAVES.

Shelter Rock.		Half Way.		Timberline.		Krummholz.	
NaOH	pH	NaOH	pH	NaOH	pH	NaOH	pH
cc		cc		cc		cc	
0.00	4.17	0.00	4.20	0.00	4.10	0.00	3.62
1.10	4.59	1.10	4.70	1.10	4.58	1.10	3.94
2.20	5.39	2.20	5.65	2.20	5.40	2.20	4.45
3.30	6.15	3.30	6.49	3.30	6.15	3.30	5.27
4.40	6.72	4.40	7.00	4.40	6.62	4.40	6.14
5.51	7.16	5.51	7.48	5.51	7.07	5.51	6.64
6.61	7.60	6.61	8.02	6.61	7.43	6.61	6.98
7.71	7.88	7.71	8.56	7.71	7.75	7.71	7.42
8.81	8.40	8.81	8.99	8.81	8.08	8.81	7.82
9.91	8.77	9.91	9.44	9.91	8.39	9.91	8.15
11.01	9.10	11.01	9.80	11.01	8.66	11.01	8.49
12.11	9.41	12.11	10.15	12.11	8.92	12.11	8.83
13.21	9.68	13.21	10.42	13.21	9.20	13.21	9.15
14.31	9.95	14.31	10.67	14.31	9.44	14.31	9.42
15.41	10.20	15.41	10.87	15.41	9.68	15.41	9.76
16.52	10.43	16.52	11.02	16.52	9.92	16.52	10.10
17.62	10.60	17.62	11.14	17.62	10.14	17.62	10.35
18.72	10.78	18.72	11.24	18.72	10.34	18.72	10.60
19.82	10.35	19.82	10.92	19.82	10.50	19.82	10.80
20.92	11.05	20.92	11.41	20.92	10.69	20.92	10.95
22.02	11.16	22.02	11.49	22.02	10.85	22.02	11.08
				23.12	10.98		
				24.22	11.04		

TABLE 19.

Titration of a 10cc Sample of Sap, July 23, 1923.

YOUNG LEAVES

Shelter Rock.		Half Way.		Timberline.		Krummholz.	
NaOH	pH	NaOH	pH	NaOH	pH	NaOH	pH
cc		cc		cc		cc	
0.00	3.90	0.00	4.11	0.00	3.20	0.00	3.17
1.10	4.22	1.10	4.73	1.10	3.40	1.10	3.36
2.20	4.74	2.20	5.95	2.20	3.62	2.20	3.65
3.30	5.61	3.30	6.83	3.30	3.96	3.30	4.08
4.40	6.24	4.40	7.55	4.40	4.38	4.40	4.94
5.51	6.73	5.51	8.62	5.51	5.50	5.51	6.37
6.61	7.16	6.61	9.54	6.61	6.84	6.61	8.15
7.71	7.75	7.71	10.17	7.71	7.67	7.71	9.78
8.81	8.45	8.81	10.63	8.81	8.50	8.81	10.48
9.91	8.90	9.91	10.92	9.91	9.24	9.91	10.92
11.01	9.56	11.01	11.10	11.01	9.93	11.01	11.20
12.11	10.12	12.11	11.25	12.11	10.50	12.11	11.40
13.21	10.44	13.21	11.37	13.21	10.86	13.21	11.52
14.31	10.70	14.31	11.48	14.31	11.10	14.31	11.64
15.41	10.94	15.41	11.57	15.41	11.28	15.41	11.70
16.52	11.10	16.52	11.65	16.52	11.42	16.52	11.76
17.62	11.20	17.62	11.73	17.62	11.52	17.62	11.80
18.72	11.34	18.72	11.78	18.72	11.60	18.72	11.88
19.82	11.40			19.82	11.70	19.82	11.92
20.92	11.49			20.92	11.78	20.92	11.96
22.02	11.58			22.02	11.86	22.02	11.98

TABLE 20.

Titration of a 10cc Sample of Sap, August 6, 1923.

Timberline.				Krummholz.			
Chloroform Treated.		Frozen.		Chloroform Treated.		Frozen.	
NaOH	pH	NaOH	pH	NaOH	pH	NaOH	pH
cc		cc		cc		cc	
0.00	3.40	0.00	3.43	0.00	3.05	0.00	3.10
1.10	3.74	1.10	3.75	1.10	3.35	1.10	3.40
2.20	4.19	2.20	4.26	2.20	3.72	2.20	3.76
3.30	5.26	3.30	5.50	3.30	4.31	3.30	4.45
4.40	6.63	4.40	6.66	4.40	5.90	4.40	5.82
5.51	7.96	5.51	7.93	5.51	7.40	5.51	7.32
6,61	9.27	6.61	9.32	6.61	8.90	6.61	8.75
7.71	10.28	7.71	10.50	7.71	10.07	7.71	10.18
8.81	10.95	8.81	11.10	8.81	10.70	8.81	10.94
9.91	11.21	9.91	11.36	9.91	11.04	9.91	11.20
11.01	11.40	11.01	11.52	11.01	11.25	11.01	11.36
12.11	11.54	12.11	11.65	12.11	11.42	12.11	11.50
13.21	11.66	13.21	11.76	13.21	11.58	13.21	11.60
14.31	11.75	14.31	11.85	14.31	11.69	14.31	11.67
15.41	11.84	15.41	11.92	15.41	11.75	15.41	11.75
16.52	11.89	16.52	11.96	16.52	11.82	16.52	11.80
17.62	11.94	17.62	12.00	17.62	11.88	17.62	11.87
18.72	11.98	18.72	12.04	18.72	11.95	18.72	11.94
19.82	12.02	19.82	12.08	19.82	11.98	19.82	11.97
20.92	12.05	20.92	12.10	20.92	12.04	20.92	12.02
22.02	12.08	22.02	12.12	22.02	12.05	22.02	12.09

TABLE 21.

Titration of a 10cc Sample of Sap, August 24, 1923.

Shelter Rock.		Half Way.		Timberline.		Krummholz.	
NaOH	pH	NaOH	pH	NaOH	pH	NaOH	pH
cc		cc		cc		cc	
0.00	3.81	0.00	3.86	0.00	4.46	0.00	3.58
1.10	4.09	1.10	4.26	1.10	5.37	1.10	4.17
2.20	4.54	2.20	4.80	2.20	6.40	2.20	5.53
3.30	5.19	3.30	5.29	3.30	6.96	3.30	6.61
4.40	5.84	4.40	6.30	4.40	7.56	4.40	7.34
5.50	6.37	5.50	6.75	5.50	8.26	5.50	8.41
6.61	8.80	6.61	7.13	6.61	8.94	6.61	9.23
7.71	7.13	7.71	7.58	7.71	9.56	7.71	10.20
8.81	7.58	8.81	8.16	8.81	10.14	8.81	10.70
9.91	8.12	9.91	8.80	9.91	10.66	9.91	10.94
11.01	8.62	11.01	9.63	11.01	10.95	11.01	11.10
12.11	9.16	12.11	9.98	12.11	11.14	12.11	11.23
13.21	9.70	13.21	10.35	13.21	11.28	13.21	11.35
14.31	10.20	14.31	10.65	14.31	11.40	14.31	11.45
15.41	10.56	15.41	10.85	15.41	11.51	15.41	11.55
16.51	10.82	16.51	11.02	16.51	11.60	16.51	11.63
17.62	11.01	17.62	11.18	17.62	11.69	17.62	11.66
18.72	11.17	18.72	11.29	18.72	11.75	18.72	11.71
19.82	11.25	19.82	11.40	19.82	11.80	19.82	11.78
20.92	11.36	20.92	11.50	20.92	11.85	20.92	11.85
22.02	11.45	22.02	11.60	22.02	11.90	22.02	11.90

TABLE 22.

Titration of a 10cc Sample of Sap, September 24, 1923.

Shelter Rock.		Half Way.		Timberline.		Krummholz.	
NaOH	pH	NaOH	pH	NaOH	pH	NaOH	pH
cc		cc		cc		cc	
0.00	4.15	0.00	3.85	0.00	3.46	0.00	4.25
1.10	4.55	1.10	4.32	1.10	4.56	1.10	4.81
2.20	5.15	2.20	5.14	2.20	6.69	2.20	5.77
3.30	5.85	3.30	6.19	3.30	7.20	3.30	6.63
4.40	6.42	4.40	6.72	4.40	7.90	4.40	7.22
5.51	6.90	5.51	7.22	5.51	8.37	5.51	7.75
6.61	7.41	6.61	7.83	6.61	8.80	6.61	8.25
7.71	7.94	7.71	8.35	7.71	9.32	7.71	8.70
8.81	8.40	8.81	8.97	8.81	9.81	8.81	9.09
9.91	8.85	9.91	9.52	9.91	10.30	9.91	9.58
11.01	9.12	11.01	9.97	11.01	10.57	11.01	10.08
		12.11	10.36	12.11	10.78	12.11	10.43
		13.21	10.65	13.21	10.92	13.21	10.72
		14.31	10.80	14.31	11.07	14.31	10.90
		15.41	10.98	15.41	11.16	15.41	11.05
		16.51	11.10	16.51	11.24	16.51	11.15
		17.62	11.23	17.62	11.30	17.62	11.23
		18.72	11.30	18.72	11.38	18.72	11.30
		19.82	11.38	19.82	11.40	19.82	11.38
		20.92	11.49	20.92	11.50	20.92	11.45
		22.02	11.55	22.02		22.02	11.53

TABLE 23.

Titration of a 10cc Sample of Sap, October 22, 1923.

Shelter Rock.		Half Way.		Timberline.		Krummholz.	
NaOH	pH	NaOH	pH	NaOH	pH	NaOH	pH
cc		cc		cc		cc	
0.00	3.86	0.00	3.81	0.00	3.84	0.00	3.80
1.10	4.10	1.10	4.18	1.10	4.45	1.10	4.34
2.20	4.65	2.20	4.80	2.20	5.42	2.20	5.10
3.30	5.29	3.30	5.70	3.30	6.24	3.30	6.15
4.40	5.97	4.40	6.33	4.40	6.75	4.40	6.80
5.50	6.50	5.50	6.83	5.50	7.17	5.50	7.40
6.61	6.98	6.61	7.30	6.61	7.52	6.61	7.81
7.71	7.40	7.71	7.70	7.71	8.00	7.71	8.25
8.81	7.91	8.81	8.23	8.81	8.40	8.81	8.63
9.91	8.32	9.91	8.76	9.91	8.80	9.91	8.96
11.01	8.76	11.01	9.02	11.01	9.18	11.01	9.28
12.11	9.18	12.11	9.64	12.11	9.60	12.11	9.65
13.21	9.63	13.21	10.04	13.21	9.91	13.21	10.04
14.31	9.96	14.32	10.42	14.31	10.22	14.32	10.35
15.41	10.28	15.41	10.70	15.41	10.40	15.41	10.59
16.52	10.50	16.52	10.85	16.52	10.53	16.52	10.72
17.62	10.74	17.62	10.97	17.62	10.65	17.62	10.86
18.72	10.88	18.72	11.10	18.72	10.75	18.72	10.97
19.82	11.00	19.82	11.20	19.82	10.86	19.82	11.05
20.92	11.11	20.92	11.25	20.92	10.90	20.92	11.12
22.02	11.20	22.02	11.34	22.02	10.98	22.02	11.20

TABLE 24.

Titration of a 10cc Sample of Sap, December 31, 1923.

Shelter Rock.		Half Way.		Timberline.		Krummholz.	
NaOH	pH	NaOH	pH	NaOH	pH	NaOH	pH
cc		cc		cc		cc	
0.00	3.65	0.00	1.98	0.00	2.43	0.00	1.52
1.10	4.14	1.10	2.35	1.10	2.76	1.10	1.95
2.20	4.84	2.20	2.98	2.20	3.21	2.20	2.55
3.30	5.58	3.30	3.80	3.30	3.86	3.30	3.24
4.40	6.21	4.40	4.56	4.40	4.56	4.40	3.76
5.50	6.78	5.50	5.29	5.50	5.24	5.50	4.62
6.61	7.20	6.61	5.85	6.61	6.07	6.61	5.36
7.71	7.68	7.71	6.44	7.71	6.58	7.71	6.15
8.81	7.72	8.81	6.94	8.81	7.01	8.81	6.78
9.91	8.47	9.91	7.25	9.91	7.40	9.91	7.30
11.01	8.87	11.01	7.76	11.01	7.82	11.01	7.70
12.11	9.32	12.11	8.23	12.11	8.11	12.11	8.05
13.21	9.70	13.21	8.59	13.21	8.44	13.21	8.54
14.31	10.04	14.31	8.90	14.31	8.70	14.31	8.88
15.41	10.38	15.41	9.25	15.41	9.02	15.41	9.25
16.52	10.60	16.52	9.60	16.52	9.36	16.52	9.66
17.62	10.89	17.62	9.95	17.62	9.64	17.62	9.95
18.72	10.92	18.72	10.25	18.72	9.90	18.72	10.26
19.82	11.05	19.82	10.48	19.82	10.20	19.82	10.42
20.92	11.16	20.92	10.67	20.92	10.40	20.92	10.60
22.02	11.24	22.02	10.82	22.02	10.56	22.02	10.73

TABLE 25.

Titration of a 10cc Sample of Sap, December 31, 1923.

Shelter Rock.		Half Way.		Timberline.		Krummholz.	
HCl.	pH	HCl.	pH	HCl.	pH	HCl.	pH
cc		cc		cc		cc	
0.00	3.05	0.00	1.75	0.00	1.63	0.00	2.14
0.85	2.97	0.85	1.74	0.85	1.60	0.85	2.07
1.70	2.89	1.70	1.72	1.70	1.54	1.70	1.95
2.55	2.80	2.55	1.62	2.55	1.46	2.55	1.87
3.40	2.70	3.40	1.56	3.40	1.38	3.40	1.78
4.25	2.61	4.25	1.50	4.25	1.32	4.25	1.66
5.10	2.46	5.10	1.40	5.10	2.00	5.10	1.55
5.95	2.32	5.95	1.21	5.95	1.04	5.95	1.45
6.81	2.11	6.81	1.00	6.81	0.84	6.81	1.35
7.66	1.81	7.66	0.78	7.66	0.59	7.66	1.20
8.51	1.55	8.51	0.74	8.51	0.45	8.51	1.09
9.36	1.34	9.36	0.70	9.36	0.37	9.36	0.93
10.21	1.19	10.21	0.72	10.21	0.30	10.21	0.75
11.07	1.12	11.07	0.79	11.07	0.30	11.07	0.65
11.91	1.07	11.91	0.80	11.91	0.45	11.91	0.60
12.78	1.04	12.78	0.81	12.78	0.49	12.78	0.55
13.62	1.04	13.62	0.81	13.62	0.52	13.62	0.55
14.48	1.02	14.48	0.81	14.48	0.57	14.48	0.55
		15.32	0.82	15.32	0.60	15.32	0.61
		16.18	0.82	16.18	0.62	16.18	0.65
		17.03	0.83	17.03	0.62	17.03	0.65
		17.88	0.84	17.88	0.65	17.88	0.66
		18.73	0.85	18.73	0.64	18.73	0.68
		19.58	0.85	19.58	0.64	19.58	0.68
		20.43	0.85	20.43	0.63	20.43	0.70
		22.13	0.85	22.13	0.66	22.13	0.73
		21.28	0.85	21.28	0.65	21.28	0.73

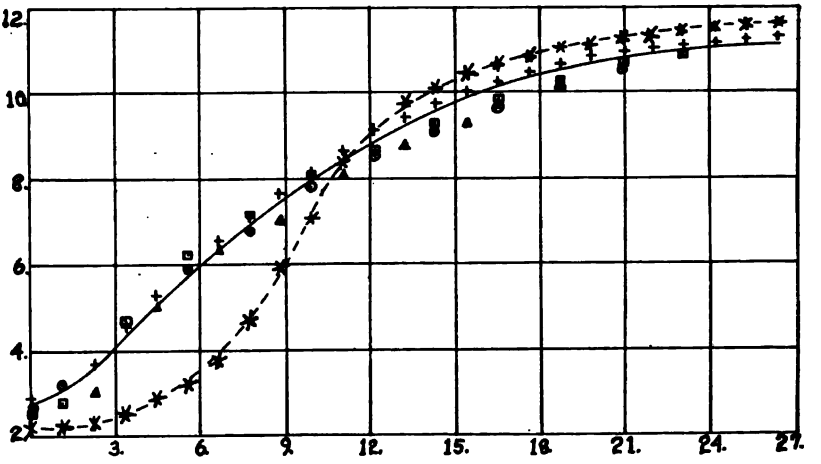

Figure 15.
Titration Curves, June 25, 1923.
Number of cc .2N NaOH is plotted as abscissae, pH as ordinates.
Old leaves. + Shelter Rock. ⊙ Half Way. ⊡ Timberline △ Krummholz.
✱ Young leaves, Shelter Rock.

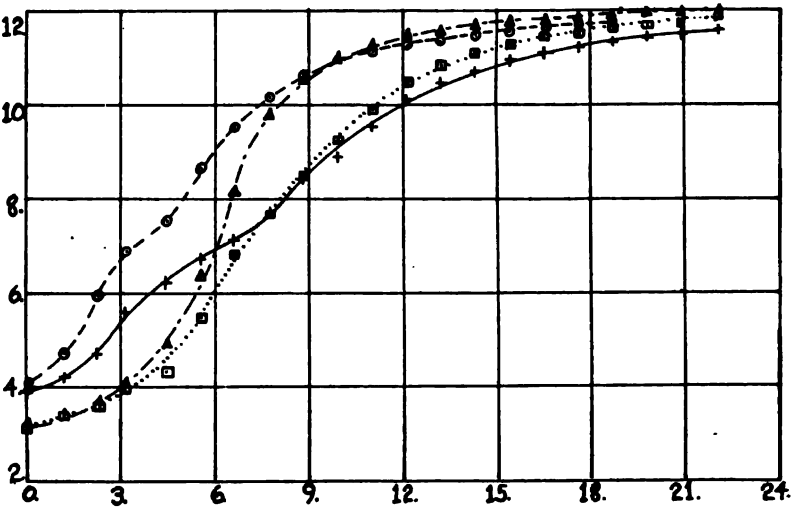

Figure 16.
Titration Curves, July 23, 1923.
(young leaves)
Number of cc .2N NaOH is plotted as abscissae, pH as ordinates.
+——Shelter Rock.⊙— — — —Half Way.⊡····· Timberline.△-·-·-· Krummholz.

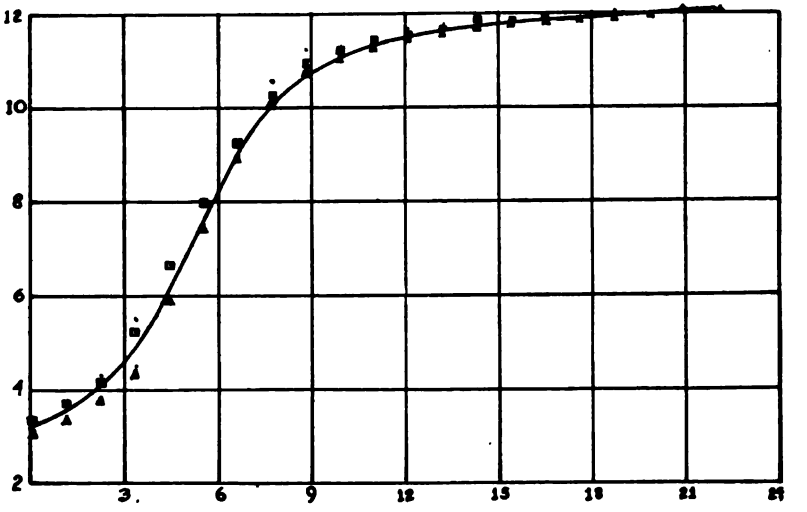

Figure 17.
Titration Curves, August 6, 1923 from chloroform treated and frozen material.
Number of cc .2N NaOH is plotted as abscissae, pH as ordinates.
⊡ Timberline, chloroform treated. △ Krummholz, chloroform treated.
Points on the curves obtained with sap from frozen material are shown, where different, as a.e

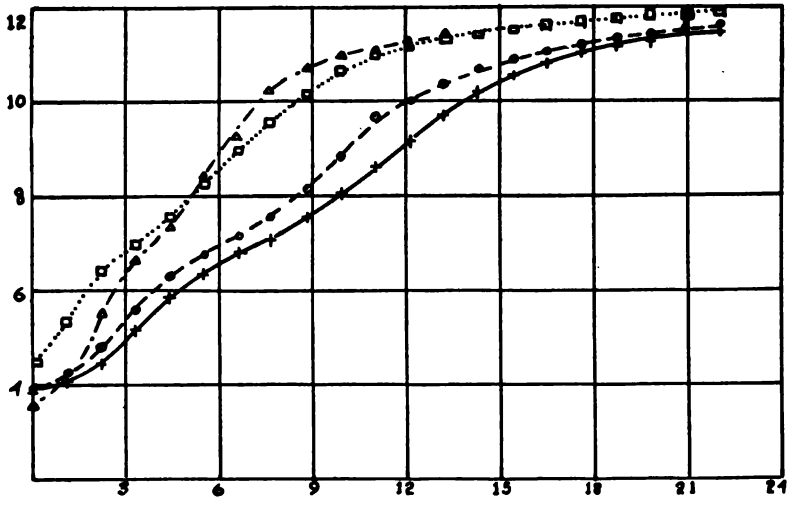

Figure 18.
Titration Curves, August 24, 1923.
Number of cc .2N NaOH is plotted as abscissae, pH as ordinates.
\+ ——— Shelter Rock. ⊙ — — — Half Way. ⊡ ····· Timberline. △ — · — · —Krummholz.

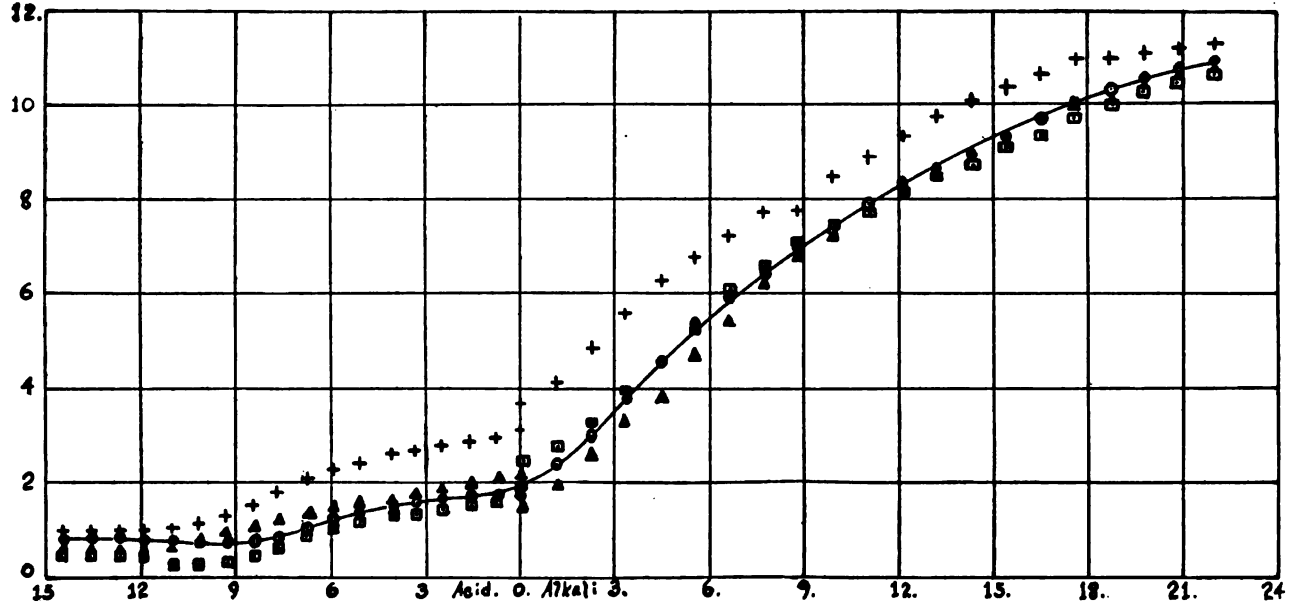

Figure 19.

Titration curves, December 31, 1923.

Number of cc .2N NaOH and HCl is plotted as abscissae, pH as ordinates.

+ Shelter Rock. ⊙ Half Way. ⊡ Timberline. △ Krummholz.

expanded from the bud for the same length of time are in striking resemblance shows that the seasonal variation is the predominant feature.

The presence of a dibasic acid in the young leaves indicates that possibly, in the spruce, this is one of the early products of photosynthetic activity and that later this is altered to produce more complex plant materials. If oxalic acid were formed as a first product it is evident that the energy required would be less than that in the formation of either formic acid or formaldehyde.

SUMMARY.

1. An attempt to study the physiological conditions of Engelmann spruce throughout its range was undertaken by physico-chemical methods.

2. Freezing was found to be an inadequate treatment of the tissue, but chloroform vapor proved accurate and effective.

3. At monthly intervals the fluids were expressed from treated leaves gathered from four typical stations throughout the altitudinal range of the tree.

4. The water and carbohydrate contents of the leaves were determined together with the density, index of refraction, osmotic pressure, electrical conductivity, initial acidity, and titration curves of the expressed leaf-tissue fluids.

5. The water content of the young leaves is high in spring, falls rapidly to a summer level, and slowly throughout the winter, being markedly low at the tree line.

6. The density of tissue fluids varies inversely with the water content, showing evidence of desiccation only.

7. The index of refraction follows closely the density curves.

8. The water content of the expressed tissue-fluid could not be obtained accurately from the refractive index sugar scale, but as computed was found to agree well with the leaf water content.

9. Freezing point determination showed an osmotic pressure low in summer, varying with altitude during the winter, and rising to a maximum in early spring.

10. The average molecular weight increased in the young leaves from summer to winter, falling in the spring.

11. The increase in average molecular weight during the autumn probably is due to a polymerization of carbohydrates and takes place at a rate which varies with the altitude of the habitat.

12. Electrical conductivity was variable and showed a removal and addition of conducting substances.

13. The total carbohydrate content of the leaves showed a minimum in the young leaves rising to a higher winter value which varied with the altitude of the stations.

14. There is a close agreement in the younger leaves between the leaf carbohydrates and the density and osmotic pressure of the expressed fluid.

15. Structural material is considered to be the total solids less the reducing substances and was found to increase, in the young leaves, at a rate proportional to the altitude of the habitat.

16. The rate of water loss was found to correspond with the dehydration of a gel if the continuous phase is considered as the structural material.

17. Tissue fluids from the higher habitats are generally more acid than the lower.

18. Titration curves with both acid and alkali show a high buffer action.

19. There is evidence, in the young leaves, of salts of dibasic acids giving way to tribasic at a slightly later period and finally assuming the highly buffered curve of the mature leaf = tissue fluid.

20. Titration curves of tissue fluid differed with the age of the leaf but showed no change with habitat.

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